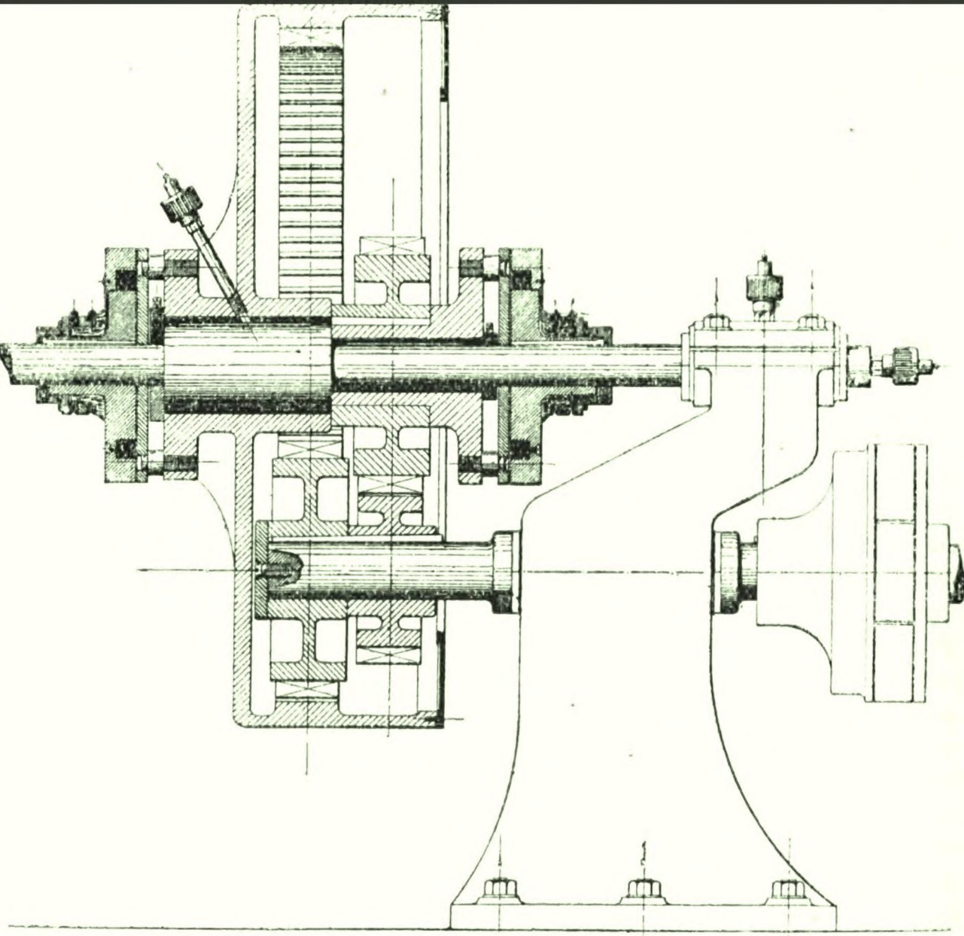

Proceedings of the Institution of Electrical Engineers

Institution of Electrical Engineers, Society of Telegraph Engineers, Society of Telegraph ...

JOURNAL

OF THE

INSTITUTION OF ELECTRICAL ENGINEERS,

INCLUDING

ORIGINAL COMMUNICATIONS ON TELEGRAPHY AND ELECTRICAL SCIENCE.

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VOL. 36.

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

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Proceedings of the Four Hundred and Twenty-ninth Ordinary General Meeting of the Institution, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, November 9, 1905—Mr. ALEXANDER SIEMENS, President, in the chair.

The minutes of the Ordinary General Meeting held on May 26, 1905, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members—

Frank Pickering.

From the class of Associates to that of Associate Members—

Louis H. Bainton.
Albert Battersby.
Thomas F. C. Forster.
Sydney E. Glendenning.
Charles H. Higgins.
Charles William Hill.
Gerard Ogilvy Nevile.
Matthew Plunkett.
Reginald P. Russell.
Bertram Gurney Stewart.

From the class of Students to that of Associate Members—

Michael Chapman.
Thomas Cleminson Evans.

Donations to the Library were announced as having been received since the last meeting from Messrs. The Accumulatoren Fabrik A. G., A. S. E. Ackermann, The Allgemeine Elektricitäts Gesellschaft, Prof. R. Arno, Mrs. H. Ayrton, A. H. Bate, A. R. Bennett, A. Blondel, W. H. Booth, W. G. Bond, F. Breisig, Charles Bright, F.R.S.E., The British Thomson-Houston Co., The British Westinghouse Electric and Manufacturing Co., The Cable Makers' Association, Cassier & Co., W. C. Clinton, The Commercial Cable Co., Constable & Co., W. R. Cooper, The Cooper-Hewitt Electric Co., J. T. Cornish, Col. R. E. Crompton, Crosby, Lockwood & Co., A. C. Curtis-Hayward, W. Duddell, Eclairage Electrique, The Electrician Printing and Publishing Co., The Elektrotechnischer Verein, Berlin, The Engineering Standards Committee, Prof. J. Epstein, W. C. Fisher, Prof. J. A. Fleming, Prof. G. Carey Foster, Ganz & Co., W. Geipel, The General Electric Co., Harper & Bros., Dr. John Henderson, T. E. Herbert, A. Heyland, W. Hibbert, F. Hope-Jones, E. Hospitalier, S. Joyce, W. R. Kelsey, C. Kinzbrunner, Körting & Mathiesen, Longmans, Green & Co.; Chambre de Commerce, du Lot; Macmillan & Co., W. L. Madgen, The Manchester Steam Users' Association, F. J. A. Matthews, C. C. Metcalfe, The National Physical Laboratory, The New York Public Library, Mervyn O'Gorman, Thomas Parker, G. D. A. Parr, W. H. Patchell, The Patent Office, Dr. F. M. Perkin, The Physical Society of London, R. V. Picou, C. Poggi, T. F. Purves, Prof. W. G. Rhodes, E. S. A. Robson, A. Russell, J. C. Sager, E. Sartiaux, The Scientific Publishing Co., T. Sewell, C. H. Sharp, Siemens Bros. & Co., Siemens & Halske, C. F. Smith, Prof. R. H. Smith, Société Française de Physique, E. & F. N. Spon, F. J. Sprague, A. Still, A. A. Campbell Swinton, The Technical Publishing Co., O. V. Thomas, Prof. S. P. Thompson, Prof. R. Threlfall, The Union Carbide Co., The United States Weather Bureau, E. J. Wade, H. Laws Webb, Joseph Wetzler, and Whittaker & Co.; to the *Building Fund* from Messrs. F. W. Dalton, E. Hutchinson, C. F. Proctor, F. H. Webb; and to the *Benevolent Fund* from Messrs. G. Allom, R. V. Boyle, W. W. Cook, H. M. Darrah, E. W. Edwardson, The Electrical Engineers' Ball Committee, A. F. Harris, C. H. Kempton, W. E. Langdon, G. Marconi, The T. C. Martin Dinner Committee, H. W. Turner, F. H. Webb, P. A. Yapp, to all of whom the thanks of the meeting were duly accorded.

Mr. ALEXANDER SIEMENS presented the Premiums and Scholarships referred to in the Annual Report of Council for the year 1905.

Mr. Siemens then vacated the Presidential chair, which was taken by Mr. John Gavey, the new President.

The President.

The PRESIDENT (Mr. John Gavey): Gentlemen, my first duty as President is to ask Sir William Preece to be good enough to move a resolution.

Sir William Preece.

Sir WILLIAM PREECE, K.C.B. (Past-President): Gentlemen, it gives me the very greatest pleasure to propose a vote of thanks to Mr. Alexander Siemens for his conduct in the chair during the past year. I can speak from experience of what he has done in the interests of

the Institution six thousand miles away. We visited South Africa together as members of the party of the British Association. He has travelled over twenty thousand miles. During the whole of that time it seemed to me that Mr. Alexander Siemens' ideas were almost entirely centralised at home, and the subject of our conversation was over and over again the work connected with this Institution. I know well that whatever he does he does well, and he has always presided over the meetings as a good chairman should preside. It gives me the greatest possible pleasure to propose that it be resolved: "That the best thanks of the members of the Institution of Electrical Engineers be given to Mr. Alexander Siemens for the very able manner in which he has filled the office of President during the twelve months, 1904–5." Sir William Preece.

Professor W. E. AYRTON: The last time Mr. Siemens and I met together in a public meeting was at Johannesburg, and there the duty was the other way about: he proposed a vote of thanks to me, so clearly it is my duty to express on this occasion not merely our thanks as a body for the able way in which he has presided at the meetings held in this room and at the Council meetings in the offices of the Institution, but also to express my personal thanks to Mr. Siemens for what he said about myself seven thousand miles away. I therefore have the greatest pleasure in seconding the resolution. Professor Ayrton.

Mr. ALEXANDER SIEMENS: Mr. President and gentlemen, I will not take up your time by making a lengthy reply. I am extremely obliged to you for the very kind manner in which you have been pleased to express the thanks of the Institution to your retiring President. I hope I may take it as an indication that my conduct in the Chair has met with your approval, which is what the President should always endeavour to obtain. Mr. Siemens.

The PRESIDENT then delivered his Inaugural Address.

INAUGURAL ADDRESS

By John Gavey, C.B., President.

In tendering my thanks for the high honour you have conferred on me, may I say that I fully recognise that I have been selected as a representative of the great body of Telegraph Engineers, the original founders of this Institution, as well, perhaps, as a representative for the time being of the new and growing telephone industry, rather than because of any merits of my own. Under the circumstances, and in view of the fact that these industries have not been reviewed recently, I propose with your permission to attempt that task in my address.

One of the penalties attached to advancing age, whether of individuals or of institutions, is the periodical loss of old friends or co-workers in the field in which we are labourers. Last year the President had to announce the loss by death of Major-General Webber. This year it is with deep regret that I have to refer to the death of Mr. W. E. Langdon, one of our earliest members, for some time Secretary and later President of the Institution. It was my good fortune to be closely associated with him from the early sixties, and I need scarcely say to those so well acquainted with his work as the members of this Institution are that in his death we have lost one of the able, energetic, and upright of our colleagues.

Another well-known figure in the telegraphic world has also passed away in the person of the late Mr. Gerhardi, a gentleman closely associated with cable enterprise, he having formed one of the group of pioneers connected with the 1856 Atlantic cable, and later having been for a long period the General Manager of the Direct Spanish Cable Company.

Before I commence the main subject of my address, I may perhaps refer to one of two questions in which the Institution is largely interested, and in which its members are taking an active part. Dealing first with the Engineering Standards Committee, and more especially with the important work entrusted to the Committee on electrical plant, the latter has appointed Sub-committees to consider the following subjects:—

1. Generators and motors.
2. Transformers.
3. Prime movers for electrical purposes.
4. Physical standards.
5. Telegraphs and telephones.
6. Cables.

7. Electrical tramways.
8. Electrical nomenclature.
9. Electric automobiles.
10. Electrical plant accessories.
11. Publications and calculations.

Some of these Committees have reported, and all the work is well in hand, but it necessarily in many cases can only progress slowly if it is to be of a permanent character. It is difficult to overestimate the advantages, both to the profession and to the public, that will ultimately result from the labours of these Committees. Again, in reference to the proposals made at the Electrical Congress held in St. Louis last year, to the effect that the revision of the existing electrical standards should be undertaken, and that an endeavour should be made to arrive at an international agreement on the subject of the standardisation of electrical nomenclature and rating of machinery, you will be glad to hear that the preliminary steps have been taken to carry out the views of the Congress, and it is to be hoped that satisfactory conclusions will ultimately be arrived at.

The art of telegraphy considered in its broadest sense as a means of conveying intelligence over distances beyond the reach of the human voice may be classed under three different heads :—

1. The communication of a limited number of definite orders or items of information by certain prearranged arbitrary signals. Under this heading may be included railway signalling, lighthouse signals, fire-alarms, and other kindred uses.
2. Communication of all classes of information by means of alphabets, either arbitrary or those in common use, including semaphore and flag-signalling, Morse and other signals, printing and writing telegraphs.
3. Communication by actual exchange of speech, the telephone.

Telegraphs for Special Requirements.

Under this heading, one of the most important of the applications of telegraphy is that of directing and controlling the movements of trains on railways. For this purpose a modification of the old semaphore telegraph was introduced in the early railway days mainly for the protection of traffic at stations and crossings. The range over which a mechanical semaphore can be worked is about 1,000 yards as a maximum, and the introduction of electricity for the working of telegraphs was soon followed by the invention of electrical miniature signals or indicators, placed in railway cabins from which the outdoor manual signals were worked in accord with the indications recorded electrically. By this means the range of the signals was extended so as to cover the whole length of a section, and this led to the practical introduction of the block system of working traffic. Successive improvements in the electrical apparatus have been introduced; for example, on single lines this apparatus is now associated with the train

staff or tablet, without which no driver is allowed to enter a section of line, and as a second staff or tablet can only be withdrawn at the far end when the first train has arrived, the possibility of two trains meeting on a section is obviated. Repeaters of various types which show the position of points, the indication of signals, the presence or absence of trains in defined localities, and other information, keep the signalman advised of all the facts with which he should be acquainted, and it is not too much to say that the safety and regularity with which the heavy railway traffic in this country is conducted is largely due to the work of the electrical engineer. Lately definite advances have been made in two directions in this field of applied electricity. In the first, complete electrical systems of actuating points and signals have been introduced, the apparatus providing interlocking gear and indicators which give the signalman positive information as to the position of every point and signal; the working being easy, rapid, and apparently reliable in so far that every eventuality and cause of trouble appears to have been foreseen and provided against. This method admits of working points and signals at distances far in excess of the manual system, such distances, in fact, only being limited by considerations of safety and convenience, and the heavy and cumbersome lines of levers that under old methods could in many cases only be worked by the full exertions of the signalman's strength can now be replaced by miniature levers which only need intelligence to work them.

In another direction, automatic methods have been designed for working outdoor signals directly by the action of the train itself, its entry, continuance in and exit from a section being faithfully followed by the appropriate movements of the semaphores. In one system sets of batteries consisting of a few cells are connected across the running rails in each section, and in all sections that are clear, the corresponding batteries actuate relays which, either through the agency of compressed air or by means of electro-motors, move and retain the semaphores at "Line clear." The entry of a train into a section short circuits the local battery, the relay tongue is withdrawn by its retractile spring and the signals are automatically placed at danger.

In a recent journey across the American continent, where hundreds of miles of desert are traversed by single lines of railway, with numerous sidings for the crossings of trains, I watched with great interest the perfect and regular working of the signals without the direct intervention of human agency. Each section was, of course, guarded by two signals, one for the up and one for the down traffic. As the train left one section for another, the signal guarding the former moved from danger to clear, whilst that guarding the latter moved from clear to danger. This method, of course, involves the necessity for bonding the rails throughout, although others have been designed which are actuated through special conductors. Automatic signals appear to meet a definite want on certain classes of railway, although no doubt the day is far distant when the trained signalman will be dispensed with at complicated junctions and stations. It is not too much, however, to say that without the various methods of electrical control

that have been devised and which are in general use, it would be utterly impossible for the great railways of the world to carry one-half the traffic they are now dealing with daily with safety and despatch. In this branch of electrical work steady progress is being made, and apart from the question of haulage the extension of the methods of electrical control will probably be considerable in the immediate future.

Fire-alarm signals have within the last few years assumed a position of considerable importance, owing to the growth of great cities, the increasing height of commercial buildings, and the large quantities of combustible material necessarily stored in the great centres of population. Starting from a simple alarum which was merely the old fire-bell worked electrically, complete systems of fire-alarms and indicators have been devised, which, when actuated from any given point, give the appropriate signals at all the fire-stations concerned, and admit of a rapid concentration of the necessary fire plant at any given spot in an incredibly short space of time. America has been in the past, and probably still is, in the forefront in the matter of fire-alarms appliances, and in my recent visit to that country I witnessed one example of the alacrity with which fire-engines can be called to any given spot. We had been visiting a number of Telephone Exchanges in New York and neighbourhood, and were motoring down one of the long avenues on Manhattan Island. As we passed one shop, I noticed that some children leaning out of a first-floor window had just set fire to the canvas sun-blind, which was burning over an area of half a square yard, so that it had only just been set alight. Before we had got out of sight of the burning blind, we were passed by a steam fire-engine, a fire-escape, and a hose-reel.

For the purpose of transmitting defined but limited items of information, for special instructions, or for making demands, innumerable electrical appliances have been designed, but there is a general tendency to replace such apparatus by telephones which simply extend the range of speech the natural method of intercommunication to any distance, and which render these subsidiary aids unnecessary.

Ordinary Telegraphs.

In considering the question of ordinary telegraphy, it may almost be appropriate to apply to it the old adage, "Blessed is the country that has no history," if this be interpreted as signifying freedom from subjects of heated debate, or controversial troubles, financial or political, which so frequently retard the development of new enterprises, it being, however, understood to imply steady progress and the full growth that is necessary to meet the requirements of the public and to spread the civilising influences of modern life into the dark corners of the world. Telegraphic statistics have been furnished on previous occasions in presidential addresses and in papers presented to the Institution, and it may not be amiss here to compare former figures with those now available.

First dealing with telegraphs for the use of railways in the United

Kingdom, I am able, through the courtesy of the various Companies, to submit a table which illustrates the growth since the year 1879, up to which date definite information was supplied in a paper read by the late Mr. E. Graves in May, 1880.

Comparison of Railway Telegraphs in 1879 and in 1904.

	1879.	1904.
Mileage of poles	14,889¼	19,484½
„ „ wire	62,009½	161,741¾
Number of telegraph instruments ...	13,128	19,978
„ telephone „ ...	Nil.	27,980
„ block „ ...	22,411	56,176
„ repeater or signal instruments	11,308	81,682

This table illustrates in a forcible manner the readiness with which our great railway companies avail themselves of the resources for the regulation and safeguarding of their traffic placed at their disposal by the electrical profession, and it is not too much to claim that the comparatively absolute freedom from serious railway disasters in this country is largely due to this wise policy.

Turning to the question of ordinary commercial telegraphy, the following figures may prove interesting :—

Telegraphs and Telephones provided by the British Post Office.

	March 31, 1880.	March 31, 1905.
Mileage telegraph poles, underground and cable	25,675	38,032
Mileage telephone poles, underground and cable	Nil.	14,898
Mileage telegraph wire	114,242	338,120
„ telephone „	40	253,521
Number of telegraph instruments ...	12,754	33,267
„ „ telephone „ ...	61	48,118

Curves showing the growth of the General Post Office telegraph and telephone plants are given in Fig. 1.

CURVES SHOWING GROWTH OF TELEGRAPH AND TELEPHONE PLANT MAINTAINED BY THE GENERAL POST OFFICE -1880 TO 1905.

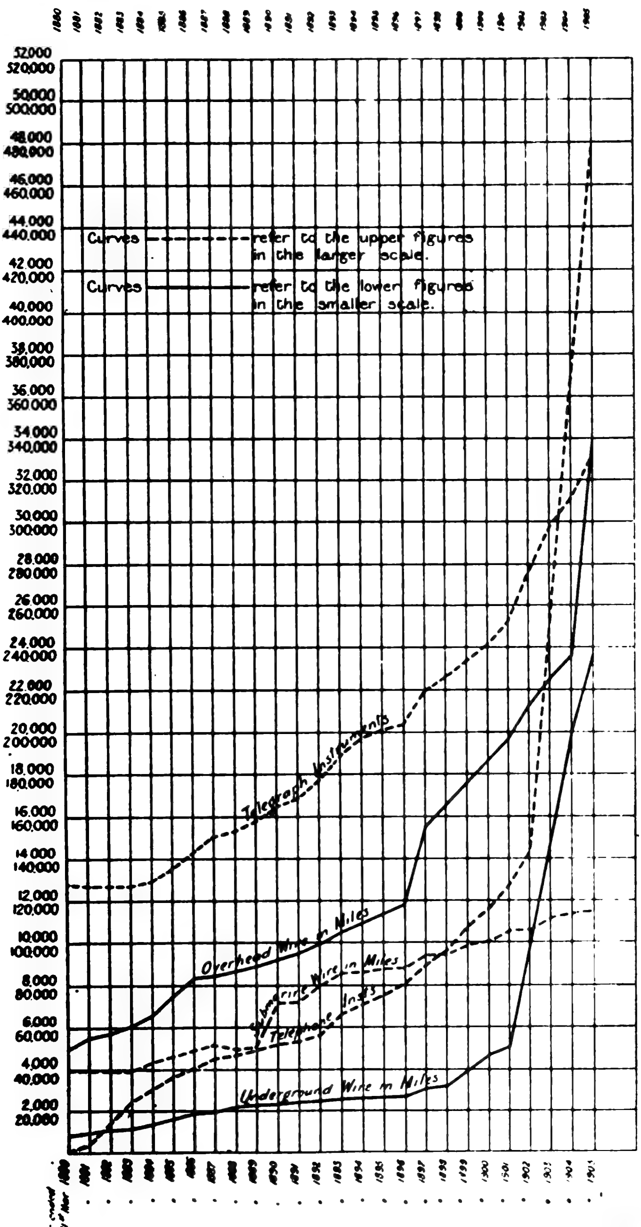


FIG. 1.

The growth of the traffic was until recently proportioned to the growth of plant, and although the ordinary telegraph traffic has now been checked by the advent of the telephone, that young and lusty child threatening to monopolise the greater portion of the short-distance work in all countries where it has free play, still for long distances the questions of cost and the physical limitations of the telephone will check the rivalry of the latter, and there appears to be but a small prospect of serious interference or serious competition between the two methods of communication after a certain critical distance is reached. It may be convenient at this point to refer to the general statistics relating to the plant in use for telegraphs and telephones in those countries from which returns are obtainable, and so far as I have been able to gather them, they were represented by the following figures, at the end of the year 1902:—

Telegraphs.

Mileage of Overhead and Underground Telegraph Wire.

Aerial.	Underground.	Total.	Instruments.
3,433,911	225,748	3,659,659	265,835

Telephones.

Mileage of Overhead and Underground Wire.

Aerial.	Underground.	Submarine.	Total.	Stations.
4,197,416	2,530,215	11,145	7,467,417	3,534,036

The statistics showing the growth of the telephone systems in the United States are perhaps the most remarkable. The following table repeats the figures given by Sir William Preece in a paper read before the Institution in 1894, and those which appear in the American Bureau of the census report for 1902:—

	1893.	1902.
Mileage of wire	532,256	4,850,486
Telephones in use	276,360	2,315,297
Telephone subscribers ...	232,140	2,178,366
Number of talks	600,000,000	5,070,000,000
Capital at par	—	348,031,058

The growth from the year 1902 to the present time has shown no signs of diminution, so that it is difficult even for the most skilled experts in the States, or those best acquainted with the general situation, to forecast the ultimate development.

As to the amount of capital expended on telegraphs and telephones, the full facts are not forthcoming, as so much of the plant has been provided by the various Governments which do not keep ordinary commercial capital accounts, but it certainly amounts to hundreds of millions of pounds sterling. A consideration of these facts, however, tends to show that whether in capital invested, in plant provided, in staff engaged, or in commercial activity, both the telegraph and its daughter the telephone show no signs of lagging behind the other branches of electrical engineering; and so far as the telephone is concerned, notwithstanding the progress it has made up to the present date, there is every reason to think that we have only seen the commencement of its development in the United Kingdom. Much of its future success depends, however, on the action of local authorities, who will have to show a more accommodating spirit than many of them have done in the past, unless they desire that the constituencies that they represent shall lag behind the remainder of the world in the enjoyment of the facilities for intercommunication that science has placed at their disposal. For these bodies to insist that all telephonic connections shall be laid underground without regard to the number of wires to be provided, to the capital cost involved, or to the fact that long telephone trunk lines must in the present state of our knowledge be provided by means of overhead wires, is to place an insuperable bar to the provision of a cheap and efficient service. In its own interest and for the good of the service which it controls a telephone administration will always place its wires underground where it is either possible to work its circuits satisfactorily or it is not absolutely uneconomical to do so, but for local authorities to insist on this method being followed in every case simply means either the stifling of the industry or its provision at a cost beyond the reach of the ordinary user. When a corporation has to provide the capital expenditure for public undertakings it takes good care to see that no waste of funds takes place, but when the cost has to be provided by others there is a tendency to make demands that would not be considered in carrying out its own works, the authorities appearing to be oblivious of the fact that the expenditure must be ultimately met in some form by those whom they represent.

If we now consider the actual apparatus by means of which commercial telegraphy is effected, perhaps the most surprising fact that strikes the observer is the predominance of the use of the ordinary Morse code and Morse apparatus throughout the world. At first it seems surprising that, notwithstanding the innumerable inventions of printing, writing, and drawing telegraphs, the original system—of course, much improved—still holds the field generally, notwithstanding the partial use of the Hughes and Baudot printing systems on the Continent of Europe. On consideration, however, it will no doubt be seen that, in comparing Morse with other systems that at first would appear to be superior, its simplicity, its relative freedom from trouble, electrical or mechanical, the ease with which its alphabet is learned and a skilled telegraphist is trained, and its adaptability to high-speed

or multiplex working, all help to maintain it in the forefront, and undoubtedly these qualities will for a long time prevent or delay its general replacement by other types of instrument where the speed of working that is necessary is not greater than can be achieved by an operator manipulating a key. Where high-speed automatic Morse apparatus, however, is in use, the want of a means of automatic transcription which would save the labour and delay of manual transcription has long been felt, and extremely promising systems have been devised whereby the problem has been solved in two different ways. In one, which was recently illustrated in a paper read before the Institution, a perforated slip is used for transmission, as in the ordinary Wheatstone system, but instead of the signals being received in Morse characters at the far end, a second slip is perforated, the exact counterpart of the original; this is placed in an automatic typewriter which prints the message on ordinary type. Two different methods of applying this system are now under the consideration of the Post Office. In others the transmission is effected by means of a perforated tape, the message, however, being printed by the receiving instrument, either by a direct impression from a type-wheel, or in one case by a photographic reproduction of each letter as the type-wheel revolves.

It is interesting to note how the practice in the ordinary telegraph service has materially benefited by the development of other branches of applied electricity. Thus for testing and localising faults, and in order to obtain control over the large mass of wires entering the principal offices in this country, these were formerly attached to screw terminals fixed in a test box, which was bulky and which occupied much valuable space in a costly building. The practice in the Post Office now is to terminate these wires on telephone jacks, and to provide for connections for testing, crossing, or other purposes by means of plugs and flexible cords, the modern arrangement only occupying one-third the space of the old type. Again, the extended introduction of secondary cells charged from lightning plant by means of motor generators has resulted in the last few years in the abolition of about 150,000 primary cells in the Post Office service, this change leading to a proportionate saving of space, and to a great economy in generating energy and in upkeep. Again, the great extent of modern London necessitates a very considerable amount of local telegraphic traffic. The number of inter-Metropolitan messages, viz., those from one part of London to another, some time ago amounted to 27,000 per diem. These were all re-transmitted at the Central Office, for it was obviously impossible to provide direct connecting wires between every one of some 600 telegraph offices. The Post Office therefore determined to revert to the system of switching lines through to one another as required, a method which had proved a failure when tried on long and costly trunk circuits, as these could obviously deal with a much larger percentage of traffic when a constant stream of messages was fed into them than was possible when switching connections had to be made. Where local circuits are concerned which are short and

inexpensive, and in the majority of cases not filled with traffic, the conditions are altered, and it is a wise policy to increase the number of wires where necessary and to save the delay and cost of re-transmission. A special switching board based on telephonic lines was therefore designed to meet telegraphic requirements, and a section providing for 138 lines was fitted up at the Central Telegraph Office and brought into use experimentally on November 13, 1902. Now any office connected to the switch which wants to communicate with another similarly connected merely calls the latter, and the switch clerk hearing the call simply joins the two lines through in the manner adopted for telephonic service. Suitable signals are provided to indicate when lines are engaged, and the number of wires to important offices has been increased. In designing the arrangement, provision has been made for working all the wires from a secondary battery installed in the Central Telegraph Office, so that the large number of primary cells previously installed in each office has been dispensed with. The result has been so satisfactory that the whole of the Metropolitan circuits are now being treated in a similar manner, and this handling of 18,000 messages twice over each day is about to be entirely obviated.

In submarine cable work the same progress may be noted as in other branches of telegraphy. The growth in half a century is represented by the following figures :—

1852	87 nautical miles
1892	139,594 „ „
1902	212,894 „ „

and it goes on without interruption.

Types of submarine cable have in practice not been materially changed, with the one exception of the air spaced submarine cable designed for telephone purposes by Mr. Willoughby Smith, one of which was laid by the Post Office between Nevin, in North Wales, and Newcastle, in Ireland, in the year 1892. The problem of devising submarine cables for long-distance telephones is, however, still to be solved. The longest telephone cable of the old Paris type was laid by the Post Office in the year 1902 for communication between London and Brussels. It is 47 knots in length, and this is about the practical limit of distance over which satisfactory telephonic speech is possible under existing conditions when allowance is made for the addition of the connecting land lines and of the local subscribers' plant.

As one of the results of cable enterprise, it may not be inappropriate here to refer to the extended knowledge of the character and constitution of the sea bottom which has been derived from the extensive soundings and surveys that have been made in the Atlantic and Pacific Oceans, preliminary to the laying of deep-sea cables. On a reference to Admiralty charts, the track of deep-sea cables can be followed along the continuous lines of soundings at short intervals which appear where cables have been laid, whereas other portions of the sea bottom are comparatively uncharted. I have especially

in mind some of the admirable charts and reports prepared by Mr. R. E. Peake in connection with cable enterprises with which he has been associated.

Wireless Telegraphy.

Wireless telegraphy, so called, has attracted a great deal of intermittent attention for many years past. The various possible methods of communication between two localities not directly connected by wire may be divided under five heads :—

1. Leakage across the earth or water between two parallel wires erected on opposite sides of a position which has to be bridged.
2. Electro-magnetic induction between coils placed vertically or horizontally.
3. The combination of the two above systems by the erection of two parallel overhead wires connected to earth at their extremities.
4. Electrostatic effects from vertical conductors.
5. The Hertzian system.

Many attempts have been made to establish communication across rivers, arms of the sea, etc., by the first method, and they have met with varying success, but the system is one the application of which has a limited scope.

The second method has but a limited range; it has only been rendered possible by the use of telephones, but inasmuch as the effective energy available for signals diminishes as the cube of the distance between the coils, the limit beyond which no signals can be received is very rapidly reached.

The third method, which, prior to the invention of the Hertzian method, was fully investigated by the Post Office, has met with a certain measure of success, and at the present time there are two installations still at work in this country. One of them connects Rathlin Island with the mainland at Bally Castle, the parallel wires being at an average distance of eight miles apart. The second instance is an installation establishing communication between the Skerries, a series of rocky islets off the coast of Holyhead, with the telegraphic service on Holyhead Island itself. The parallel wires are at an average distance of three miles apart. The latter installation is worked telephonically, *i.e.*, the wires are fitted with telephone transmitters and receivers, and telephonic speech is actually transmitted from wire to wire.

The fourth system of communication by purely electrostatic effects without the emission of free waves has not been developed on a practical scale.

The fifth, or Hertzian, system has created world-wide interest, and its development in the course of the last few years has been very marked. As is well known, the method is based on the classical researches of Hertz; it was made possible in the first place by the

original inventions of the coherer by Branley, improved later by Lodge, and finally developed into a practical system by Marconi.

It may be of advantage to briefly review the gradual development of the art from the date of Marconi's early work. It will, no doubt, be remembered that after a period of experiments, first in Italy, then in this country, a crucial trial was made in the year 1896, under the auspices of the Post Office, across the Bristol Channel, from Lavernock Point, first to the Island of Flatholm, and then to Breamdown, near Weston-super-Mare. At that period, what has by some been termed the "Whip Crack Method" only had been tried; that is to say, a powerful spark coil was connected, one terminal to the vertical conductor, the other to the earth. This arrangement emits a very powerful impulse which is damped down almost immediately, and it is probably the first single impulse alone which affects the receiver at a distance. Elementary attempts at tuning were made by various experimenters during this period, but the art was not sufficiently developed to admit of any really useful results being obtained. The coherers were probably far too sensitive, and the difficulty experienced in the early days was rather due to their not decoherering than to their failing to respond to the electrical waves. In course of time this difficulty was remedied by the use of an oscillating transformer in the receiving circuit which admitted of the use of less sensitive coherers, and excellent results were obtained, but owing to the fact that every receiver within a certain definite range of a given transmitting apparatus responded to each impulse, and all receivers were affected by all transmitters within range, it appeared at first as though Marconi's attempt to increase the effective limit of his apparatus would tend to restrict rather than to extend the use of the system. He and others interested in wireless telegraphy, therefore, turned their attention to the establishment of syntony between the transmitting and the receiving apparatus, and a marked degree of success has attended their efforts. This syntony is usually effected by connecting one or more closed oscillating circuits to the source of energy and coupling these either direct or through an oscillating transformer with the vertical antennæ, the closed oscillating circuit and the vertical antenna being in unison, *i.e.*, having the same frequency. A closed oscillating circuit includes a capacity and an inductance, and therefore for each primary impulse a train of waves is generated. The first portion of the wave has not such an amplitude as when the Whip Crack Method is used, but this is more than counterbalanced by the effect of the long train of oscillations, which results in restricting to a great extent the visible effect to receivers tuned in harmony, other receivers not so tuned not responding when a certain critical distance is passed. In the next place, by a judicious combination of oscillating circuits with antennæ of suitable capacity, the amount of energy that can be utilised for the transmission of signals may be increased from the small limits imposed when an ordinary induction coil is used to practically any given amount—an utter impossibility with the original method of working. Of course, where a very powerful exciting system is in use, the radiating surface must

be increased proportionately, and the well-known method of multiple antennæ has been designed to achieve this end. At the receiving station, the tuning is effected by the addition either of inductance or of capacity, the receiving installation being brought into as perfect syntony with the transmitter as is possible. In addition to this, special devices have been introduced in the receiving circuit for the elimination of waves of other periodicities so that even Whip Crack transmission can to a great extent be eliminated. The effect of having the transmitting and the receiving apparatus in harmony was shown in an admirable manner by the Post Office experiments, recently carried out and described by Messrs. Duddell and Taylor, which gave graphical measurements of the energy received under both conditions.

The receiving apparatus has undergone many modifications since the original filings coherer was invented. There is, for example, the single point contact, consisting of a pointed carbon lightly resting on a slightly oxidised steel surface; the Brown radioscope, consisting of a lead electrode resting lightly on a surface of peroxide of lead; the Lodge Muirhead revolving disc, touching lightly on a mercury surface; the Schaffer, so-called anti-coherer, consisting of a fine razor slit across a silvered glass surface; the Italian Navy coherer, in which one or more globules of mercury are enclosed between carbon and steel contacts—all of which are dependent for their action on imperfect contacts; the Bolometer and electrolytic methods claimed by different inventors; and finally, Marconi's electro-magnetic receiver. Many of these have been associated with variations in the original method of combining the different electrical elements of each circuit, and have been denominated "Systems." I will not, however, enter the thorny path of attempted discrimination between those that may be considered as systems or those that can only be described as methods.

A great deal has been said by rival inventors as to the possibilities of wireless telegraphy, and some exaggerated claims have been made on their behalf which have led to counter statements by some interested in other methods of communication. Whilst on the one hand it may be fairly assumed that wireless telegraphy is not, under any circumstances, likely to supplant or even to compete seriously, with, inland methods of intercommunication, there is no doubt that there is a very distinct and important sphere of utility awaiting its further development. For intercommunication between ship and shore, and ship and ship, much has been done, although much remains to be done. For intercommunication between neighbouring coasts there is also a possible future, but this depends almost wholly on the further development of the methods of syntony or tuning. There appears to be no doubt that in cases in which the wave-lengths used on two systems differ to a considerable extent, a very marked degree of success has been obtained in the avoidance of mutual interference. Where the wave-lengths, however, are not very widely apart in frequency, there is in each case a definite range within which interference arises, and simultaneous working is impossible. That the tuning methods will be improved I think there can be very little doubt. The progress that has

been made between the year 1896, when it took a week to receive a few elementary signals over a distance of nine miles, and the present time, when such remarkable results have actually been obtained, is so great that it does not imply the possession of an unduly sanguine disposition if one ventures to predict further improvements, which may be expected to increase the freedom from mutual interference, the speed, and the reliability of this method of communication. It does not appear to be very probable that it will seriously compete with the highly developed cable communication in the near future, although it may in many instances supplement that service.

Construction.

No marked changes have taken place in the methods of overhead construction, beyond the general tendency towards the wholesale substitution of hard drawn copper for iron wire for overhead conductors. The magnetic inertia, due to the metal itself, which affects high-speed results so largely when iron wires are used is, of course, absent in the case of copper. Although the first cost is higher, the scrap value of the copper when renewed is considerable, and there is the further point that when the time arrives for converting overhead telegraph circuits to telephone uses, the appropriated conductors will at once be available. In other respects there have been, of course, various improvements in details which, however, do not need special mention.

In underground telegraphs, something approaching a revolution is in progress. It is a curious and instructive fact that the majority of the early inventors who designed or imagined methods of telegraphy contemplated the use of underground wires insulated by various ingenious methods which, however, would scarcely have proved efficacious in practice. Further, in this country, two of the great telegraph companies started with the idea of laying telegraphs underground, and very long lengths of gutta percha wire were laid in wooden casing, some of which is re-covered from time to time and is even now found to be in excellent condition. Various reasons led to the abandonment of underground work in favour of overhead lines, and little was done in later years in the direction of providing a comprehensive underground system until the great work in Germany was initiated in the seventies. Owing, however, to the high cost of gutta percha, and to its great specific inductive capacity, the extended use of this material did not commend itself to the English Government, except, of course, in large towns where underground work was imperative, for owing to the slow speed attainable on ordinary gutta percha underground wires, and the vast mass of Press matter that had to be transmitted by the Post Office, there was little temptation to indulge in a heavy expenditure with the object of replacing overhead wires by underground work, even though the overhead wires were occasionally subject to serious interruptions which no human skill or engineering foresight could guard against. The introduction of the modern multiple cable insulated by dry paper and enclosed in lead sheath has gone a long way

in the direction of overcoming both these difficulties, viz., the financial difficulty of cost and the electrical difficulty of high static capacity.

Incidentally, it may be of interest to refer to the genesis of the modern air-space dry-core cable, for details of which I am indebted to Mr. Kingsbury. It is, of course, well known that many attempts were made years ago to obtain a cheap substitute for gutta percha insulated wires, and these attempts generally took the direction of wires covered with cotton or other fibrous material enclosed in a pipe or tube, which was filled with a permanent insulator, either solid or liquid, such as paraffin wax or oil. At a later period paper was substituted for cotton, and it was proved that wires so insulated had a lower static capacity than those covered with cotton. It was at first assumed that this was due to the character of the paper used, but it was soon realised that the actual reason was that with the paper the insulating compound could not be forced into the tube so as to absolutely fill all the interstices, and that numerous air spaces existed throughout its length. From this to the use of the present form of cable was but a step. In cables of this type relatively large conductors weighing from 100 to 200 lbs. per mile can be provided with a static capacity of 0·1 microfarad per mile, and where a large number of wires have to be provided, at a total expenditure not very unduly in excess of that necessary for overhead wires.

As soon as this type of cable became available for use, the Post Office took the initial step in the construction of a line containing 76 wires enclosed in a 3 in. iron pipe from London to Birmingham, a distance of 117 miles. This line was commenced in 1897, was completed in 1899, and brought into use after preliminary experiments had been carried out with a view of determining its adaptability for the purposes of the Post Office. It was, of course, foreseen that the wires in close proximity would be subject to a certain amount of mutual disturbance, and it was doubtful to what extent this disturbance would interfere with the various methods of telegraphy in use. To provide for the worst possible case, therefore, the wires were twisted up in pairs like those required for telephone circuits, and the length of the lay of the neighbouring pairs was varied, so as to provide as far as possible for working metallic loops where necessary, either for telegraph or telephone purposes, with the minimum amount of mutual interference. The experiments proved that it was possible to work duplex on neighbouring single wires of a pair, when earthed at each end, without interference when the speed was limited to that possible with manual transmission. Quadruplex working was subject to some slight interference, but under these conditions Wheatstone working was not possible at a higher speed than 50 to 60 words per minute. The general result, however, was admirable from every point of view, and the steadiness of working and the freedom from interference by atmospheric or other causes was so great that the Postmaster-General subsequently decided to extend the London-Birmingham line to Glasgow. The question of the type of cable to be carried forward then came up for consideration. From London to Birmingham there

were 38 pairs of wires. In the interval many types of paper insulated cables had been devised with a view to obtain a form suitable for use with earthed circuits, and therefore to a great extent free from mutual induction, either static or electro-magnetic, the ultimate outcome of which was the design of a conductor insulated with paper, each insulated conductor lapped with copper foil and the whole of the wires cabled and sheathed with lead.

It was finally determined to continue the London-Birmingham section northwards by the laying of a cable containing 37 pairs of the ordinary paper insulated wires as a core surrounded by 29 copper screened single-wire conductors: this decision being arrived at after it had been proved conclusively that where quadruplex or high-speed circuits were required, it was possible to obtain satisfactory working with the quadruplex or Wheatstone on a metallic loop, and to superimpose thereon a key duplex. Where quadruplex is therefore in use on a long circuit, 6 channels are obtained on two wires, or a Wheatstone duplex and a key duplex can be worked on each loop. Again, it has been proved that between London and Glasgow, by the use of a repeater at Preston or Warrington, a speed of 200 words per minute can be obtained on these wires with Wheatstone apparatus, so that it will be observed that a great step has been made by the substitution of a moderately economical system of underground work susceptible of working at high rates of speed, for the old costly and slow methods which the use of gutta percha involved where land telegraphy was concerned.

The main underground line from London to Glasgow will be completed by March or April, 1906, and other important sections of main line, notably a section from London to Chatham, are in hand.

Here, perhaps, I may fitly state that the Post Office and the general public owe a debt of gratitude to our British manufacturers of electrical plant for the energetic and able manner in which they meet all requirements, however onerous, made upon them. They spare neither time, trouble, nor expense in an endeavour to meet the most difficult specifications, and it is not too much to say that without their assistance this record of modern progress could not have been realised. I render this tribute all the more willingly because it has lately become the fashion for irresponsible writers in the public Press to decry the British manufacturer as old-fashioned, not up to date, and not ready to meet modern requirements. I can truthfully say I have nowhere met reputable firms exhibiting this spirit.

A few specimens of air-spaced telegraph cables which illustrate the gradual development of those now in use are placed on the table, and members may wish to inspect them later.

TELEPHONES.

Not the least remarkable of the modern developments of electrical engineering is the extraordinary growth of the telephone service throughout the whole of the world. Subsequent to the year 1860, when Reis invented his musical telephone, it was thought by the majority of electricians that no further approach towards the attainment of articu-

late speech could be made. The possibilities attending the use of loose contacts, at that time the most dreaded enemy of the electrical engineer, had not been foreseen, and the conclusion was generally arrived at that it would be impossible to devise a transmitter free from the defect of causing actual breaks in continuity so as to admit of the delicate curves necessary for the transmission of articulate speech being reproduced electrically. Bell's invention in 1876 was received almost in a spirit of incredulity, and when in the following year it was brought to this country it was looked upon as a marvellous development. Although as a receiver the instrument was even then practically perfect, its powers as a transmitter were weak, but the invention of the microphonic transmitters in 1877, by Edison in America and Hughes in England, speedily led to the development of the telephone on commercial lines. Kingsbury has told us in his paper, read before the Institution in January, 1895, how in 1878 the first telephone exchange was started in London, the old telegraph umschalter switch having been utilised for the purpose. For many years the service was necessarily imperfect, gauged by modern standards, as for a long period open wires carried overhouse had to be resorted to, and single-wire circuits were practically a matter of necessity at large exchanges, the result being that cross talk could not be eliminated, and comparatively inefficient transmitters were used in order to reduce the amount of this disturbance. The invention and development of the modern paper insulated air-space cable with its low electrostatic capacity led to the general adoption of the one main factor in satisfactory telephone working, viz., the use of well insulated metallic circuits so constructed as to be free from cross talk. This opened the door to the use of the very best types of telephone transmitter, and paved the way for the successive improvements in exchange plant that are so marked a feature in modern systems, and that have led to the extraordinary increase in telephone statistics that has taken place in the last ten years.

As the result of successive inventions, a steady and rapid improvement in the indoor plant available for Exchange work has taken place, and so far as modern telephone switch is concerned, these improvements have been wholly in the direction of reducing the amount of talk on the part of the operator that was necessary under the old conditions. This has been brought about by the provision of a complete system of automatic signalling whereby she is kept abreast of her work, so that, with the exception of asking for the number of the subscriber who is wanted, there should in all ordinary cases be no need for conversation between the subscriber and the operator, this being accompanied by a corresponding increase in the speed of working. In fact, one system goes so far as to render it unnecessary even to ask for the number of the subscriber required, that information being printed by the caller on a Morse slip. This tendency to reduce the operator to a species of intelligent automaton naturally suggests the possibility of the entire elimination of the operator, and the introduction of suitable automatic apparatus at the Exchange. Several very ingenious methods of attaining this end have been devised,

and one system has achieved a certain measure of success in America, several Exchanges of some magnitude having been equipped with apparatus of this type. Two or three small automatic switches have been installed in Europe, but no European telephone administration has yet faced the problem of establishing an extensive automatic system for the use of towns in which large Exchanges are required. To review the reasons for the hesitation so far displayed by the more important of the telephone authorities would be to introduce controversial matter which would be out of place. The subject is, however, not exhausted, for it is being carefully studied at the present time in America, and there appears to be some possibility of development in the not distant future that may lead to important modifications in present methods.

One word may here be added as to the magnitude of the plant required for modern Exchange working.

There appears to be an occasional tendency to look upon telegraphs and telephones as a little apart from serious engineering undertakings, because in the actual transmission of telegraphic signals or telephonic speech minute currents measured in milliamperes and microamperes generally suffice. The movement of electric railway trains and street cars or electric cranes, of electric gun training machinery, and other similar mechanical work, impresses the imagination far more vividly than does the still, small voice that is heard in a telephone, but when modern telephone practice is considered it will be found that in the complexity of the system, the amount of electrical energy used for the purpose of signalling and the extent of the works undertaken, a telephone system regarded from the engineering standpoint is in no degree behind any other electrical enterprise. As an illustration, it may be stated that in carrying out the preliminary arrangements for serving about one-third of the Metropolitan area the Post Office has already excavated 565¼ miles of trench, it has laid 1,251 miles of duct, it has provided 162,216 miles of wire, and the weight of copper buried in the London streets amounts to 2,200 tons; and this apart from the work carried out by the National Telephone Company in the same districts.

The secondary cells used for signalling and common battery speaking at the Central Exchange have a capacity of 5,500 ampere hours, and the number of glow lamps in use on the existing Central Exchange for signalling purposes is 25,000. It may be added, however, in illustration of the growth of the system, that the first contracts for the Post Office system in London were entered into on February 24, 1900, and the first Exchange was opened on February 24, 1902, with 169 subscribers, the ultimate capacity being 14,000 subscribers. Its growth was so rapid that within two years of its being opened it became necessary to commence the installation of a second Exchange which is being constructed within the same building and which will shortly be opened with a further capacity of 20,000 subscribers, a corresponding enlargement of the general appliances in the building being involved.

Perhaps the most remarkable development that has taken place in the whole world is that which in the last few years has arisen in

America. In the early portion of my address I referred to certain statistics furnished by the American Bureau of the census. The growth in the number of telephones provided by the American Telegraph and

GROWTH OF BELL COY'S SUBSCRIBERS, 1876 TO 1905.

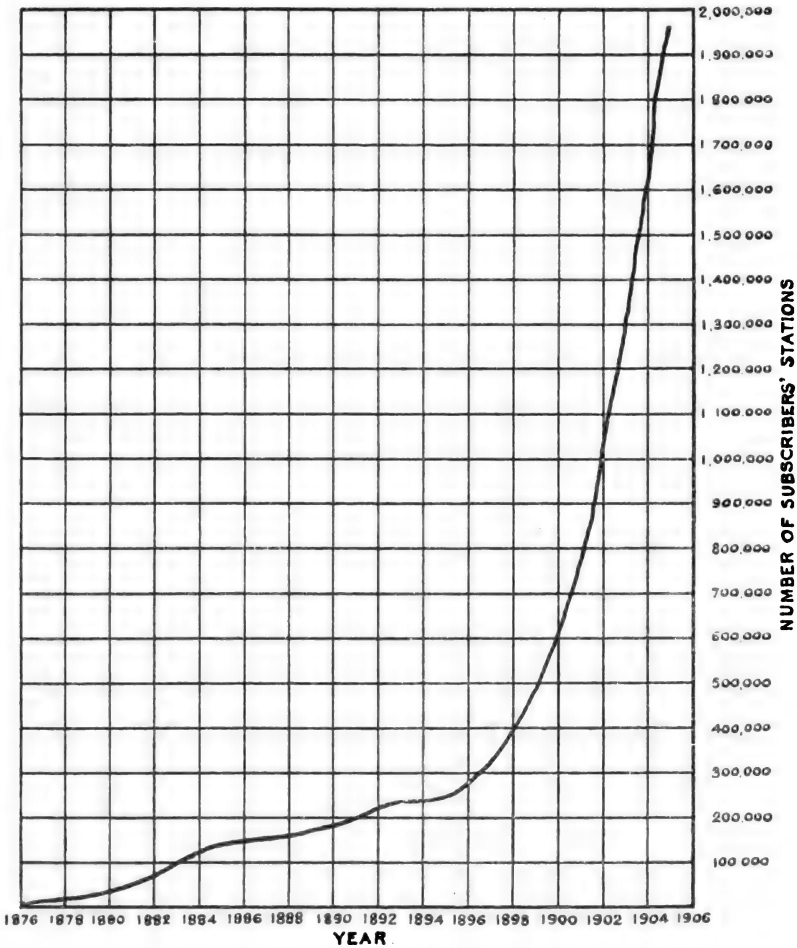


FIG. 2.

Telephone Companies (commonly known as the Bell Companies) in the United States of America, as shown by the curve in Fig. 2, is absolutely startling. I visited America in 1898, at which date the Company had about 400,000 stations open. I have just returned from another

visit, and find that they have 1,950,000 stations at work, an increase of 1,450,000 in seven years, and they are still progressing at the same pace. Domestic and other reasons appear to foster the use of the telephone. The number of private houses provided with these modern appliances bears a very high ratio to the number of business premises in which they are installed. All the large hotels have telephones in every room, a central switch connected to the main Exchange being located in the hall. Large shops have installations varying from 250 to 1,000 telephones, these in some cases being scattered along the counters so that customers can telephone from their houses direct to the shop assistant whom they know to be acquainted with their wants or fancies.

The most important adjunct to the Local Exchange system is the trunk line, or long-distance service, as it is variously called. In 1896 the Post Office acquired, by purchase, such of the trunk lines as had been erected by the National Telephone Company and not only did it at once erect such additional wires as were necessary to provide a comprehensive service covering the whole country, but it has been engaged year by year in erecting additional trunks. Such is the favour with which the trunk service generally is regarded, that it is difficult to keep pace with the demand for additional wires. The annual growth is represented by the following figures:—

	Circuits.	Miles of wire in actual use.
Year ending March 31, 1896 ...	165	17,500
" " " 1897 ...	804	47,855
" " " 1898 ...	877	55,721
" " " 1899 ...	953	63,109
" " " 1900 ...	1,029	69,713
" " " 1901 ...	1,116	76,831
" " " 1902 ...	1,165	83,302
" " " 1903 ...	1,309	93,473
" " " 1904 ...	1,418	102,799
" " " 1905 ...	1,604	112,744

The determination of the distance over which telephonic speech is possible on various types of telephone circuit is a question of the greatest theoretical and practical interest, and it is one that has

received much careful consideration. The theoretical investigations of Clerk Maxwell, Kelvin, Oliver Heaviside, G. A. Campbell, Pupin, and others have done much to elucidate the problem under consideration, and we are now, I think, fairly well acquainted with the various factors that govern and limit the range of possible speech, and the methods by which these limits can, under favourable conditions, be extended; such, for example, as the partial neutralisation of the effects of static capacity by the addition of self-induction. In connection with the transmission of telegraphic signals through long cables, it will be borne in mind that Lord Kelvin, in the year 1854, enunciated the K. R. law, and at first attempts were made to apply this law to telephonic work. Now the simple K. R. law applies with some degree of accuracy to telephonic cables in cases in which wires of approximately the same gauge are concerned, but it fails in cases in which the electrical constants R K and L vary materially, and it is quite inapplicable as part of a general law to open lines where self-induction is a marked factor or where the conductivity of the wires varies materially. As illustrating this, the following observations made by the able staff of the Bell Companies in America show to what extent the K.R. Law fails:—

TABLE OF EQUIVALENT CIRCUITS.

Type of Circuit.	Loop resistance per mile. Ohms.	w/w capacity. Micro-farads.	Long-distance standard of commercial talk. Length equal to 1,200 mls. No. 8 B.W.G. open wire. Miles.	Long-distance standard of commercial talk. K. R.	Local Service standard of commercial talk. Length equal to 750 miles No. 8 B.W.G. open wire. Miles	Local Service standard of commercial talk. K. R.
100 lbs. Copper aerial	17·73	·007825	388	20,884	253	8,880
176 " " "	10·26	·008218	560	26,443	360	10,927
425 " " "	4·08	·008978	1,200	51,027	750	20,604
American Standard Cable	88·00	·051	41·8	7,842	26	3,034
Boston-Lynn Cable...	41·80	·042	73·2	9,407	45·5	3,635
London-Birmingham Cable	11·00	·063	115·0	9,165	71·5	3,543

It was quite evident that the K. R. Law failed owing to no account being taken of the important factor L, and on comparing a large number of results obtained over Post Office lines of different character the following rough empirical formulæ were designed to meet ordinary cases. As will be seen further on, these were found to give fairly concordant results within certain limits.

Aerial lines of 100 lbs. copper and upwards :—

$$M = 210 \sqrt{\frac{l}{KR^{1.75}}}$$

For unloaded paper cables—

$$M = 85 \sqrt{\frac{l}{KR}}$$

where M = limits in miles.

Before dealing with the more recent formulæ now in use for determining the limiting distances of speech, it may be well perhaps to refer briefly to the theoretical conditions which affect the transmission of telephonic impulse. The ordinary electrical conditions in a circuit which may modify or effect an impulse *in transitu* are the following :—

A. Resistance.
B. Electrostatic capacity.
C. Self-induction.
D. Insulation.
E. Abrupt and numerous alterations in the circuit which may cause reflection.
F. Interference from extraneous cause, *i.e.*, static or magnetic induction, leakage, etc., from neighbouring circuits.

When an electrical impulse is started in a conductor, if the latter had neither resistance, capacity, nor self-induction, and if the insulation were perfect, the wave would move on without attenuation or distortion. The effect of resistance or of uniformly distributed low insulation, however, results in a definite attenuation which increases with the length of the circuit, and, further, the effect of capacity is to cause the wave to spread out, both forwards and backwards, this "tailing," as it is termed, not only increasing the attenuation by lowering the amplitude, but causing distortion of the wave itself and also of the neighbouring impulses, with which it interferes. This distortion eliminates the higher notes and harmonics, and in extreme cases causes the voice to lose its characteristic tone, and ultimately to become inarticulate.

Now it is obvious that it is a matter of extreme importance to ascertain to what extent each of these elements affects in the most material manner the limiting distance of speech, and much light is thrown on this subject by actual experiments made over long lines of various characters, overhead, underground, and submarine. As the result of many trials, it is found that with long circuits free from external disturbance, such as underground wires, the actual practical limit is fixed by the loss of amplitude of the waves; in other words, by the diminution of volume rather than by the loss of articulation, although when these limits are approached it is found that articulation begins to suffer, and when the line is still further increased, the tones become

low and hoarse, and speech ceases to be practicable. This points to the fact that in actual practical work attenuation due partly to resistance, and partly to electrostatic capacity, are the dominant factors, and this attenuation when combined with disturbance from neighbouring electrical conductors actually determines the limits of speech. This view is supported by a comparison of the results obtained by calculation and those obtained by actual experiment. That in actual practice articulation is not materially affected up to the point when the volume of sound becomes too small for practical purposes is probably due to the fact that the inherent self-induction of an ordinary circuit suffices to prevent such an amount of distortion as might otherwise interfere with articulation at more moderate distance than those actually experienced. Oliver Heaviside, in his Electrical Papers, vol. ii. p. 393, showed the extremely limited range of possible speech in paper cables, assuming an entire absence of self-induction in a closely twisted up pair, and the extent to which this range is extended even by the limited self-induction which obtains in normal conditions. He thus early anticipated the practical results already referred to. At all events, calculations giving the limiting distance of speech on various types of conductors, based on attenuation only, are found to agree with actual experimental facts. The remaining factors, although they must have some influence on the results, can in practice and under conditions which obtain in a simple metallic circuit be neglected.

As a preliminary to the determination of the limits of speech, it is necessary to ascertain the degree of volume and articulation, or in other words the audibility, which may be accepted as satisfactory, and further to establish standard circuits with well-known constants of R L and K to which all lines may be reduced either by calculation, by experiment, or preferably by both. For this purpose, both in America and England, one of the types of ordinary lead-covered paper insulated cables, in which the above constants are measurable, has been selected, and the dimensions of the English standard cable, which agree closely with American figures, are as follows:—

	Gauge S.W.G.	Weight per mile.	Diameter Mils.	R. (loop). Ohms.	K wire to wire. Microfarad.	L.	Insulation.
English	20	20 lbs.	36	88	0·056	0·001	200

Now in actual practice a telephone on an exchange circuit must be thoroughly effective whether joined through to another circuit a few yards in length or connected to a long-distance line some hundreds of miles long, but obviously it is quite unreasonable to expect that the conversations shall have the same volume and articulation in both cases, and of course when a long-distance line approaches the limits at which it is possible to converse, it is absolutely essential that the apparatus and lines shall be in the best working order, that each speaker shall raise his voice and speak distinctly and close to the transmitter, and that both correspondents shall have their apparatus in fairly silent rooms.

In considering this question from the practical point of view, it is necessary to take into account the variable conditions under which long-

distance speech is frequently held. The insulation of long overhead wires may in this climate drop in extreme cases to a figure as low as the metallic resistance of the conductors themselves; slight inductive noises are never really absent, and occasionally they preponderate. In a paper on trunk telephones which I read before the Institution in November, 1896, I pointed out how difficult it was to obtain even an approximately perfect static balance between a telephone circuit and neighbouring wires subject to rapidly varying potentials. Again, the human element largely affects the result; indistinct and muffled speech, disregard of regulations in the use of apparatus, partial deafness, apparatus in noisy and unsuitable localities, all tend to limit long-distance speech, and to render the application of very accurate determinations difficult. In fact, it may be said that the limits of error in calculation, whether the empirical or the more accurate formula referred to later are used, are less than the limits of variation in practice, and that as in all engineering matters there must be a considerable factor of safety to ensure satisfactory intercommunication. Telephone administrations have carefully considered what are the extreme limits of effective commercial speech under the last-named conditions, and it is generally considered that from 42 to 46 miles of the above-named standard cable is the effective commercial limit, although conversations have been held by experts over 60 miles of such a cable.

This being accepted, two methods can be adopted for determining the limits of speed on various types of telephone circuits.

In the first place, the attenuation is calculated for various types of cable, say by Pupin's formula, in which the insulation R is so high that attenuation by leakage can be neglected, or by Campbell's formula for overhead wires when leakage must be assumed. By the use of these formulæ, tables of ratios which express the relative equivalence of each type of circuit to the standard cable are prepared, and the limit of commercial speech having been fixed in miles of standard cable, the limit on all other types of conductors is a simple matter of calculation.

The second method, of course, consists in a direct comparison of all existing types of line with a standard cable. A lengthy series of experiments has been made on all classes of Post Office conductors, overhead, underground, and submarine, and they have been balanced by means of a standard apparatus to their equivalent lengths of actual standard paper cable. The equivalent lengths have also been calculated by Pupin's and Campbell's formulæ, and the table on page 28 shows the degree of concordance in the results, as also corresponding figures based on calculations made by means of the empirical formulæ already referred to.

It will be observed that the calculated limits of speech based on attenuation agree absolutely with experimental results on all the underground cables. There are, however, variations in the calculated and observed results obtained on overhead lines, and these are no doubt due to variations in insulation and to slight disturbances which affect the audibility materially when approaching the limits,

TABLE OF EQUIVALENTS BASED ON ATTENUATION AND EMPIRICAL FORMULÆ RESPECTIVELY.

TESTS MADE WITH THE STANDARD APPARATUS DESCRIBED IN THE SCHEDULE TO THE AGREEMENT, DATED 1905, BETWEEN THE POST OFFICE AND THE NATIONAL TELEPHONE COMPANY.

Type of Line.	Constants per mile of loop.			No. of miles of various types of conductors giving equal transmission to 1 mile 20-lbs. cable. (Calculated from Pupin's and Campbell's formulæ.)	Limiting distance based on speech limit of 43 miles standard cable. (Calculated from preceding column.)	Limiting distance based on empirical formulæ.	Limiting distance based on speech limit of 43 miles standard cable. Observed experimental values.
	R. Ohms.	K. M.F.	L. Henries.				
				Miles.	Miles.		
Underground A.S.P.C. Cable.							
10 lbs. Cable...	175·64	0·07	0·001	0·61	26	25	26
20 ,, ...	86	0·055	0·001	1·0	43	43	43
40 ,, ...	42	0·056	0·001	1·47	63	66	63
70 ,, ...	25	0·063	0·001	1·83	·79	72	—
100 ,, ...	17	0·058	0 001	2.45	105	91	—
150 ,, ...	11·7	0·065	0·001	2·95	127	113	127
200 ,, ...	8·75	0·07	0·001	3.5	151	150	—
Submarine Cable.							
160 lbs. Cu. and 300 lbs. G.P. per knot	12·9	0·12	0·00165	2·3	99	97	88
G. P. Quad.							
40 lbs. Cu. per mile ...	43	0·128	0·001	0·95	41	36	39
Aerial Wires.							
100 lbs. Cu. Open	18	0·00808	0·0039	8·45	363	357	—
150 ,, ,, ...	11·9	0·00839	0·00376	11·7	503	490	473 Means of several trials.
200 ,, ,, ...	9	0·00862	0·00366	14·7	632	613	626 Means of several trials.
300 ,, ,, ...	6	0·00893	0·003545	21	903	844	903 Means of several trials.
400 ,, ,, ...	4·5	0·00919	0·00344	26·1	1,122	1,056	1075 Means of several trials.
600 ,, ,, ...	2·97	0·00958	0·00331	36·8	1,582	1,443	1582 Means of several trials.
800 ,, ,, ...	2·25	0·00987	0·00322	45·8	1,969	1,804	Not determined owing to disturbance.

Another method of investigating the problem of telephonic transmission has been undertaken at the Post Office, and although the experiments are not complete, I propose to attempt to show some of the results which exhibit graphically the attenuation which in practice takes place under varying conditions. Two circuits have been selected, one consisting of a mile of the standard cable already referred to, and the second consisting of twenty miles of similar cable. A Duddell's oscillograph has been used for observing simultaneously the curves due to the action of the induction coil at the transmitting end and the corresponding curves at the receiving end of the circuits. A number of letters, both vowels and consonants, have been rapidly spoken into the transmitter, and the respective transmitted and received curves for each have been recorded in the usual photographic manner. (See Plates I. to V.)

The results are not, I fear, quite so distinct as I could wish, but there are considerable difficulties in manipulation, which perhaps may be overcome later. One, for instance, is due to the great difference in amplitude of the curves at opposite ends of the long length of cable. The spot of light in the transmitting end travels over a longer range than at the received end, and the photographic exposures, therefore, vary in the inverse ratio of the amplitudes. However, I hope enough will be seen to make this line of investigation clear and to prove to some extent the accuracy of the foregoing data. It will be seen that on the one-mile length the curves at opposite ends are almost counterparts one of the other, the difference of amplitude being inappreciable, and all the irregularities of each transmitted curve being faithfully reproduced at the distant end. Where, however, the longer length of cable is introduced the difference of amplitude is most marked, and although it is perhaps somewhat more difficult to compare the shapes of the two curves, they still bear a substantial resemblance one to the other.

There is one marked effect which I hope you can observe. In the reproduction of certain letters, not only is the amplitude of the curves at the transmitting end of the twenty-mile length greater than on the one-mile length, but the details, *i.e.*, the variations in each section of a letter curve are more distinct in the former than in the latter. So far I cannot account for this effect quite satisfactorily. It may be due to reflection, for it is a coincidence that twenty miles is exactly the half of a wave length in this type of cable with a frequency of 1,200. At all events, this seems to explain, or if not to coincide with, the occasional difficulty one experiences in maintaining satisfactory talk over very short lines which has hitherto been considered as being due to speaking too loudly.

It will no doubt be observed that this method of reproducing the curves due to specific sounds affords a great improvement on the old phonautographic method. In the latter the sharp peaks on each curve which may be observed on the best of the slides just shown are all rounded off in most of the published illustrations, and no other result can be expected where levers are used to increase amplitude.

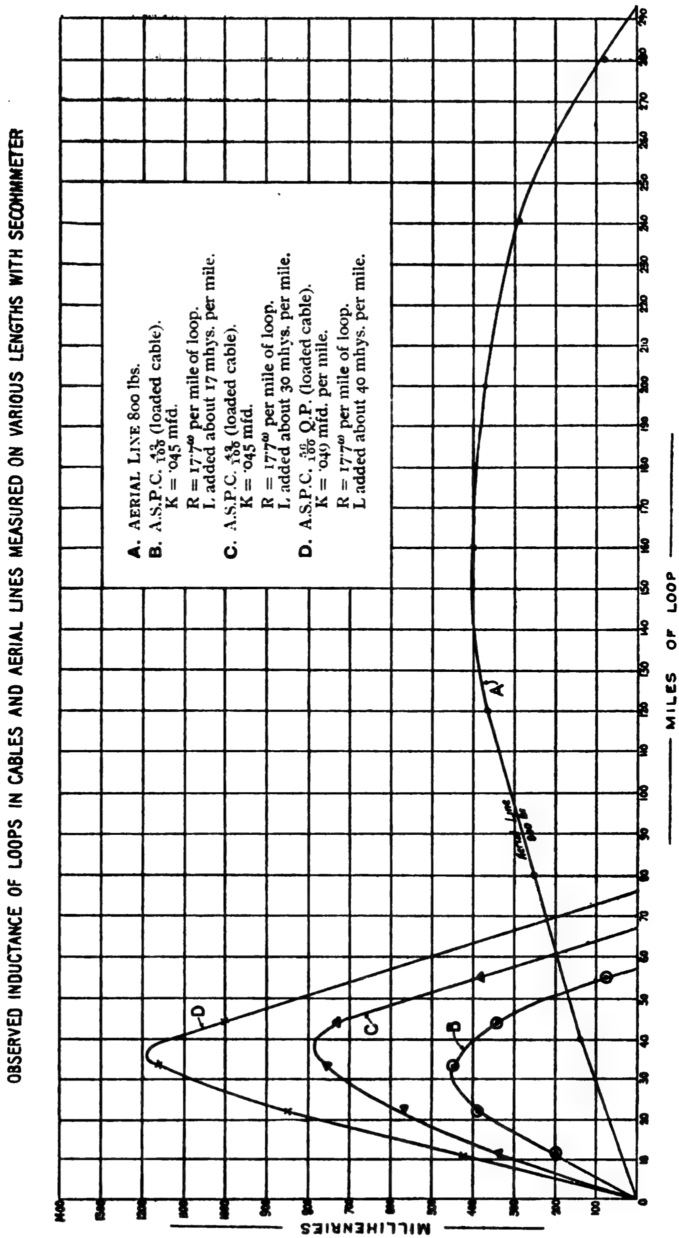

OBSERVED INDUCTANCE OF LOOPS IN CABLES AND AERIAL LINES MEASURED ON VARIOUS LENGTHS WITH SECOMMETER
A. AERIAL LINE 800 lbs.
B. A.S.P.C. 43/100 (loaded cable).
K = ·045 mfd.
R = 17·7ω per mile of loop.
L added about 17 mhys. per mile.
C. A.S.P.C. 43/100 (loaded cable).
K = ·045 mfd.
R = 17·7ω per mile of loop.
L added about 30 mhys. per mile.
D. A.S.P.C. 56/100 Q.P. (loaded cable).
K = ·040 mfd. per mile.
R = 17·7ω per mile of loop.
L added about 40 mhys. per mile.
MILLIHENRIES
MILES OF LOOP
Aerial Line 800 lbs
A
B
C
D

FIG. 3.

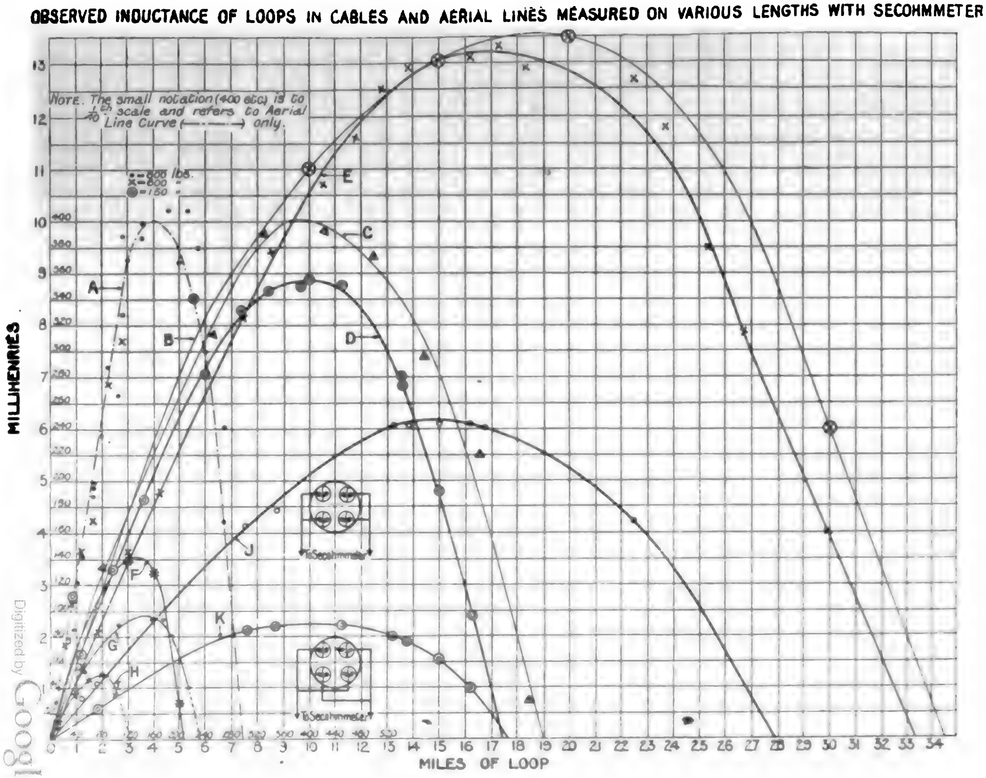


FIG. 4.

A. AERIAL LINE ($\frac{1}{10}$th Scale).

B. A.S.P.C. $\frac{18}{200}$ and $\frac{18}{100}$ Q.P.
K = ·045 mfd. per mile (200 lbs.).
R = $8{\cdot}8^{\omega}$ per mile of loop (200 lbs.).

C. A.S.P.C. $\frac{18}{100}$ Q.P.
K = ·045 mfd. per mile.
R = $17{\cdot}7^{\omega}$ per mile of loop.

D. A.S.P.C. 100 lbs. $\frac{38}{100}$ Q.P.
K = ·049 mfd. per mile.
R = $17{\cdot}7^{\omega}$ per mile of loop.

E. A S.P.C. 200 lbs. $\frac{58}{100}$ Q.P.
K = ·068 mfd. per mile.
R = $8{\cdot}8^{\omega}$ per mile of loop.

F. 40 lbs. G.P. Quad.
K = ·13 mfd. per mile.
R = 45^{ω} per mile of loop.

G. 40 lbs. A.S.P.C.
K = ·06 mfd. per mile.
R = 45^{ω} per mile of loop.

H. 20 lbs. A.S.P.C.
K = ·05 mfd. per mile.
R = 90^{ω} per mile of loop.

J. A.S.P.C. 400 lbs. $\frac{58}{100}$ Q.P. (sides bunched).
K = ·13 mfd. per mile.
R = $4{\cdot}4^{\omega}$ per mile of loop.

K. 400 lbs. $\frac{58}{100}$ Q.P. (diagonals bunched).
K = ·17 mfd. per mile.
R = $4{\cdot}4^{\omega}$ per mile of loop.

The oscillographic method of producing these curves should be of considerable use in the study of vowel and other elementary sounds.

It is, of course, obvious that any marked improvement in the normal types of telephone apparatus will tend to extend the ranges given in the tables. Further, it will be observed that these ranges are based on a 43-mile limit of standard cable, although under favourable conditions, and with expert users of the telephone, much longer distances are practicable. These limits also presuppose that the telephone is joined directly on to the line, and they have to be cut down when the Exchange apparatus and the Subscriber's line are added, by an amount equal to their equivalent mileage.

Such tables as these admit of a determination of the gauge and type of conductor necessary to serve any given locality, it being borne in mind first that in a country like Great Britain, where main trunk lines pass through towns of considerable size every few miles apart, it is difficult to carry heavy gauge wires intact from one extremity to the other; *i.e.*, lighter gauge open wires and underground work have to be introduced in sections to overcome obstacles, and, further, that telephonic communication differs from telegraphic in so far as this, that where the former is concerned any given town may require to be put through to any other town within the general telephonic range of the service. It is, therefore, obvious that in laying out and adding to a system of telephone trunk communication, the extended use, either of small gauge conductors or of underground work generally, is absolutely inadmissible. Such conductors with limited range can only be used under well-defined conditions. It follows that to provide an efficient and economical service it is necessary to make a careful study of the country as a whole and to lay out the trunk lines in such a manner as to deal with the maximum traffic with the minimum weight of copper, and to provide for general intercommunication by the shortest possible lengths of trunk circuit.

It will, of course, be borne in mind that the foregoing remarks apply to unloaded circuits, *i.e.*, those not fitted with artificial inductances.

Incidentally, the accompanying curves may be of some interest. They represent measurements made with a secohmeter, on various types of loop, and they illustrate very graphically the fact that on short lengths the self-induction predominates largely over the capacity. As the length of circuit increases the curve first rises, but as the capacity effects increase more rapidly than the inductances, the curve reverses and falls until a point is reached in which the self-induction and the capacity neutralise one another.

I have already referred to the question of increasing the self-induction of telephone lines by the addition of induction coils at definite lengths. In America the question has been dealt with by Dr. Pupin, and considerable work has been done in that country in the direction of loading underground cables, as it is termed. The Post Office took up the subject at an early date in connection with its main underground lines, and a marked measure of success has already been

The Curves (Plapaper cables having a loop resistance of 88 ohms and a wire to wire capacity of 0·056 mieer curves at the receiving end.
The respective cdell's oscillograph.

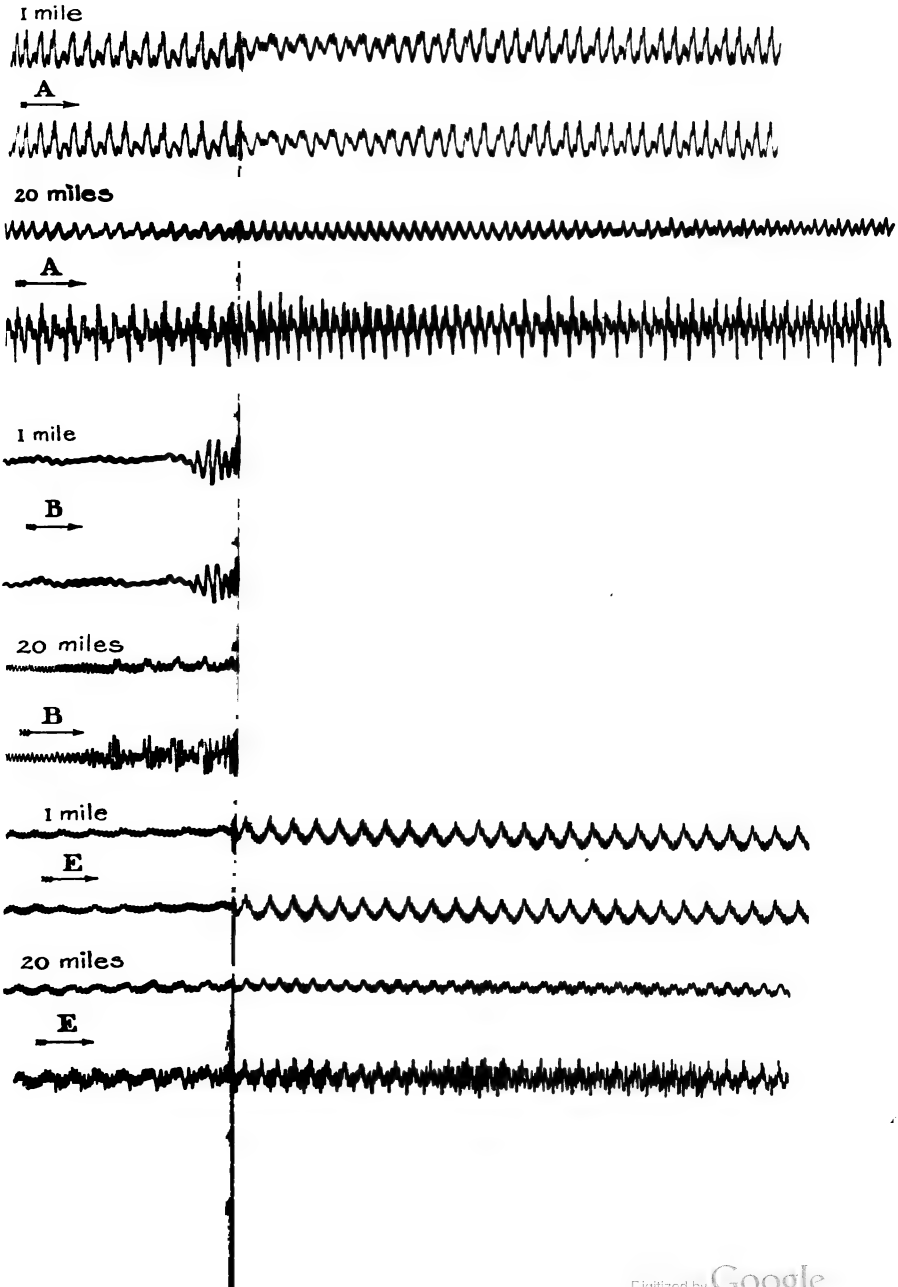


FIG. 5.—CITY EXCHANGE. Vertical side of Main Frame and Lead Cables to Intermediate Frame.

FIG. 6.—CITY EXCHANGE. Front of Switchboard, showing Multiple Field (during installation).

FIG. 7.—CITY EXCHANGE. Multiple Cables at rear of Switchboard (incomplete).

FIG. 8.—CITY EXCHANGE. Multiple Cables for 15,500 Subscribers' Lines.

FIG. 9.—CITY EXCHANGE. Cabling above Relay, Meter Racks, and to Lamp Resistance Racks.

FIG. 10.—CITY EXCHANGE. Meter Rack (rear).

FIG. 11.—CITY EXCHANGE. Relay Rack (front).

FIG. 12.—CITY EXCHANGE. Intermediate Frame (before Cabling).

FIG. 13.- CITY EXCHANGE. Intermediate Frame. Switchboard Cables in position, but not connected.

obtained. In one case, that may be taken as an illustration, a cable containing 56/100 lb. conductors, was loaded by the insertion of coils at intervals of a mile; the original factors were $R = 17$ ohms, $K = 0{\cdot}053$ microfarad, $L = 1{\cdot}4$ millihenries, and the total added inductance per mile amounted to 40 millihenries, the original R being raised to 21·34 ohms per mile by the addition of the coils. The equivalent range of speech was, however, increased from 66 to 176 miles. In the Post Office experiments on its long-distance lines so far, the use of iron in any portion of the coils has been found to be deleterious as compared with coils without iron cores. True, the volume of sound was always materially raised where iron was used, but at the cost of articulation, whilst a judicious addition of self-induction without iron always improved both the volume and the articulation.

Very satisfactory results have, however, been obtained in America and in Germany by the use of ring-coils with extremely fine iron cores, and further progress in this direction may be anticipated.

On this subject a valuable paper was read by Dr. Hayes at the recent Congress in St. Louis, in which he shows how under suitable conditions the attenuation in long lines is materially diminished by the addition of suitable inductances properly spaced. His paper is a valuable contribution to our knowledge of the subject.

Experiments with overhead conductors have not proved so satisfactory as with underground cables. The variation in the insulation of the open wires upsets the balancing due to the coils, and lightning troubles have affected the coils. For the present, at all events, this method of increasing the range of open conductors of limited gauge cannot be considered so satisfactory as the corresponding results with underground work, and opinions as to the future of open wire loading appear to be somewhat divergent.

Unsolved Problems.

Finally, there are the unsolved problems in connection with electrical methods of communication to consider. These are neither few nor unimportant. Dealing with the different heads of my address in order, the telegraphic problem is by no means finally solved, notwithstanding the years which have elapsed, and the growth of the system since its introduction. A means whereby telegraphic messages can be received at high rates of speed in type or written character ready for immediate issue to the public or the Press, appears to be one of the desiderata of the future. That this need is fully realised is shown by the ingenious inventions that have from time to time been received and experimented with by the most important of the telegraphic administrations in Europe and America. Incidentally I think I may truly say that one of the most painful duties imposed on the heads of a telegraph service is the rejection of inventions on which an untold amount of skill and labour have been expended, but which for one reason or another are not fully adapted for practical requirements. I have reason to hope, however, that we are now within a measurable

distance of a satisfactory solution of one branch of the problem just referred to.

Next, in wireless telegraphy, there is the difficult problem of perfect tuning which will obviate all mutual disturbances between different wave-lengths, and in addition it can, I think, scarcely be said that we have arrived either at finality in the matter of wireless receivers. In fact, the impression left on one's mind after a study of all the methods so far evolved is that we are even now far from having a thoroughly effective or reliable receiving arrangement, if we compare the reliability of wireless with that of telegraphic or telephonic communication.

Then in telephony there are at least two fundamental problems which await solution. First, the invention of an effective telephone relay or repeater; and, secondly, a method of extending the range of communication in submarine cables.

In reference to the existing practical limits of speech on circuits of different types, it will be evident that these limits are such that it is not always possible to meet the requirements of the public over Continental areas of great extent, or in cases where long submarine cables are necessary. Until recently all attempts to design a satisfactory telephone relay had failed, but the American Telegraph and Telephone Company have now under trial an instrument termed an Exalter, which, when placed in a suitable position on a long line, materially improves the communication. I tried this recently between New York and Chicago, and I hope shortly to have an opportunity of experimenting with it on our long-distance lines and cable circuits. It is the first step that costs, and we may now look forward hopefully to other developments.

Notwithstanding the very great advances made in the modern switchboard, the problem of affording intercommunication between very large numbers of subscribers is by no means finally solved. The largest multiple that can be fitted in practice on one board does not exceed 20,000 lines, and not only in London, but in several American towns, provision is being made in one building for numbers varying from 40,000 to 60,000 telephones, two or three separate exchanges being provided in one building. That this duplication and triplication of exchanges is the final solution of the problem no one would, I think, venture to predict, and as I have already hinted, there are indications that the difficulty may be met in another manner.

The submarine cable problem for telephonic use is not an easy one, as gutta percha, which, so far as our present experience goes, must be used in some form, has such a relatively high electrostatic capacity, that it has not been found practicable to use it for really long cables, and the problem of loading, which at first sight would appear to offer a solution of the difficulty, has not yet been met in a satisfactory manner. Again, although much has been done in the direction of improving the methods of telephone switching—and only those can judge what progress has been made who are familiar with, for example, the modern central battery board, and can compare its working with that of the older forms—still we are by no means near finality, and there are

possible improvements and modifications looming in the not distant future which may profoundly modify our present practice.

Finally, I have little doubt that the progress of electrical means of intercommunication will in the future go on unchecked, and that those associated with and responsible for such progress will in the course of the next few years bring about such developments that they will be in a position to compare in no unfavourable manner the advance of these particular branches of our work with that which we can foresee in all other branches.

I cannot conclude this address without rendering due tribute to the able and indefatigable officers on my staff who have designed many of the improvements and have conducted the numerous experiments which have led to the results I have endeavoured to lay before you; and I have also to thank Mr. Gill, the Engineer-in-Chief of the National Telephone Company, for his hearty co-operation in determining the limits of telephonic speech.

I desire also to refer to the admirable work, both theoretical and practical, of our American *confrères*. Not only have they from the first occupied the premier position in the development of the telephone, but their readiness to impart their knowledge to those who desire to inquire into their methods deserves the warmest praise from those who have been privileged to get into close touch with them.

Professor Silvanus Thompson.

Professor SILVANUS P. THOMPSON: Mr. President and gentlemen, there is an unwritten law of this Institution by virtue of which it falls to one of the Past-Presidents to move a certain resolution after listening to the Presidential Address. It is very difficult, after listening to a Presidential Address bristling with so many facts, so many statistics, so many figures, so many things out of the common which we do not have to deal with in our everyday lives, to carry away a connected idea of what it has all been about. We are apt to be bewildered. We have been looking at the very beautiful curves that have been shown, and I have been wondering what they mean, whether those long lines referred to letters or sounds—whether the K, for example, was the sound of K as it occurs in speech or the sound of the letter pronounced *kay*. I rather suspect that a long series of those vibrations was due to the latter or vowel part, which was not the sound of K at all; it was the sound of Ā. However that may be--and we shall have full information hereafter on the point—it is a matter of most intense interest; and those of us who have studied the problems of recording sounds by other and older methods for years past will hail with delight a new method, especially if it promises to give us more perfect detail in the recording of sound. My mind goes back to the experiments made twenty years ago by the late Professor Fleming Jenkin, with Professor Ewing as his assistant, when he unravelled for the first time, by aid of the phonograph, some of the mysteries of recorded sound, and told us of the then extraordinary curve lines, about which even now we know so little. We sincerely hope that the researches of Mr. Gavey and of his staff of assistants at the Post Office will prove to be of real scientific

Professor Silvanus Thompson.

value, quite apart from any commercial importance that they have, and I have no doubt whatever that that is very great. We have learned a great deal to-night. I cannot carry the tenth part of the figures he has given in my head. I think I heard something about there being seventy million messages sent in a year, and that over 150,000 cells have been saved in the Post Office by some method of switching telegraph lines as though they were telephone lines by jacks somewhere in the Post Office. But I came to the conclusion that there was at the Post Office, and now at the head of this Institution, an extremely able personage, who had a very able staff at his command, and who directed them with uncommon energy and skill. I therefore venture, sir, to express the hope, in the form of the official language in which it has been placed in my hands, that you will kindly allow us to print your discourse in our Journal in order that we may have the benefit of studying it at leisure. The motion I have to put before the Institution is: "That the best thanks of the Institution be accorded to Mr. John Gavey for his most interesting Presidential Address, and that, with his permission, the Address be printed in the Journal of the Proceedings of the Institution."

Mr. Swinburne.

Mr. JAMES SWINBURNE: Mr. President and gentlemen, it is my pleasant duty to second very cordially Dr. Thompson's vote of thanks to the President. In the Presidential Address Mr. Gavey called our attention to the importance of what some of us are rather apt to call small engineering, and he has taught us to realise more thoroughly than we have done before that there may be an infinite amount of engineering in dealing with what are almost infinitesimally small things. If there is room for people like Kelvin and Heaviside to work in submarine telegraphy, and people like Lodge and others in wireless, there is plenty of room also, in the best engineering sense, for everybody to work at these matters now. Telegraphy is not by any means an easy subject, which is played out and all settled; taking telephony and wireless telegraphy, it is really only just beginning after all. I do not know whether there are ever any advantages in listening to a sermon, but if there are, one of them is that you can apply the things said in it to other people, especially the people who were not there. I hope, therefore, that the President will grant Dr. Thompson's request, and will allow the Address to be printed. I also hope that it will be sent to all the local authorities, and I wish they could be compelled to read the particular part of it which specially concerns them. No one who has not attempted to write a Presidentia Address has any idea of the difficulty of preparing it. The requirements are very serious. The Address must be written at a particular time, whether the President wants to write it or not—and he generally does not want to write it—and it has to be interesting, not only to a particular section of the Institution, but to everybody. This requirement is one of the most difficult, but I think, if I may say so, that the President has fulfilled it absolutely. I have never heard an Address delivered when we have had such a full room all listening carefully to every word of it. Another requirement is that the Address must not be contentious, and I think we

all agree absolutely with everything that has fallen from our President's lips. I hope, therefore, we shall carry this vote with acclamation. Mr. Swinburne.

The resolution was put to the meeting by Professor Thompson, and carried by acclamation.

The meeting adjourned at 9.40 p.m.

Proceedings of the Four Hundred and Thirtieth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, November 23, 1905—Mr. John Gavey, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on November 9, 1905, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

Transfers.

From the class of Associate Members to that of Members—

Robert Percy Brousson.
Herbert William Jones.
Harry Richardson.

From the class of Associates to that of Associate Members—

Edward George Paul Bousfield.
George Henry Broom.
Charles Henry K. Chamen.
William Collins.
Samuel Irwin Crookes.
George Alfred Neild.
J. Frank Shoolbred.
Ernest Joseph Taylor.
William Alexander Wilson.

Messrs. C. P. Hammond and L. T. Healy were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

Elections.

Members.

James D. Erskine-Murray, D.Sc., F.R.S.E.
Walter Harrison Tittensor.

Associate Members.

Leolin Gordon Bain.
François Victor Bornand
Affonso de Oliveira de Albuquerque-Maranhao.
Albert C. Flesch de Nordwall.
Edward James Evans.
Austin Hopkinson.
Ernest Herman Friedrich Hotopf.
Henry Lockyer Mortimore.
Theodore Hansmann Schoepf.
Jiu Kuma Tanaka.
John Wilson.

Associates.

John Edward Bell.
John Hill-Williams.
Norman S. H. Sitwell, Captain, R.A.
George Charles Alexander Wilkins.

Students.

Winfred John A. Anderson.
Moritz Ignatz Bergl.
Colin Cooper.
Enrique de Galvez.
Reginald Danby Godden.
Edmund Eric Leigh Grundy.
Randall G. Hosking.
William Nelson Huggins.
Frank C. Moore.
Ernest Frederick Page.
Henry Hartley Pearson.
Thomas Frederick Potts.
Howard Price.
Gordon Kenitz Rouquette.
Gilbert Colville Shadwell.
Basil Milledge Venables.
Guy Wilfred Wyles.

The PRESIDENT: I have to make an announcement of a sad nature. You have all heard of the loss of the South-Western steamer *Hilda*, and no doubt you have also observed that one of the gentlemen who lost his life was Mr. G. A. Grindle, one of our old members. He had been a full member of the Institution from the early eighties. I have to ask your permission to send on your behalf a vote of condolence with his family.

The motion was carried in silence.

The meeting adjourned at 9.45 p.m.

The following paper was read and discussed :—

THE APPLICATIONS OF ELECTRICITY IN THE ROYAL GUN FACTORY, WOOLWICH ARSENAL.

By Colonel H. C. L. HOLDEN, R.A., F.R.S., Member.

(*Paper read November* 23, 1905.)

When it was suggested to me that I should put before the Institution, in the form of a paper, a description of what had been done in the matter of electric driving in the Royal Gun Factory, with which I have been associated since 1899, I felt some diffidence in complying with the request, because it did not appear that a mere description of what had been done in this direction would possess sufficient interest unless there was some notable departure from ordinary practice, since the electric driving of factories is now fast becoming the rule instead of the exception.

As far as I am aware, some of the methods I shall describe and illustrate to you are departures from the ordinary methods in vogue, and on that account I am in hopes they may be of interest, and this must be my excuse for bringing them to your notice. I do not, however, intend to confine myself entirely to methods of electrical driving, but will describe more or less briefly other applications of electricity which have been found to be of use in this particular factory.

The question of the relative merits of individual motors for driving machine tools *versus* motors driving groups of tools has often been discussed, but no hard-and-fast line can be laid down as to when either system should be used, except, perhaps, for tools which require a large amount of power, certainly not less than 10 or 15 H.P. as a minimum; but the converse of this is not true, because it may often be expedient to employ a motor of even a fraction of a horse-power for an individual machine. It comes to this, therefore, that each individual case must be considered on its own merits, and this is the principle on which I have worked.

In the case of a great many conversions of workshops to electric driving all that has been done has been to substitute an electro-motor for the prime mover previously used, be it steam, gas, or other engine, and though this may have effected an improvement in economy and other ways, it is not by any means as good as if the whole system had been remodelled with a view to electric driving throughout. I may here explain, for the benefit of the few of those present who do not already know it, that the work of the Royal Gun Factory consists of the

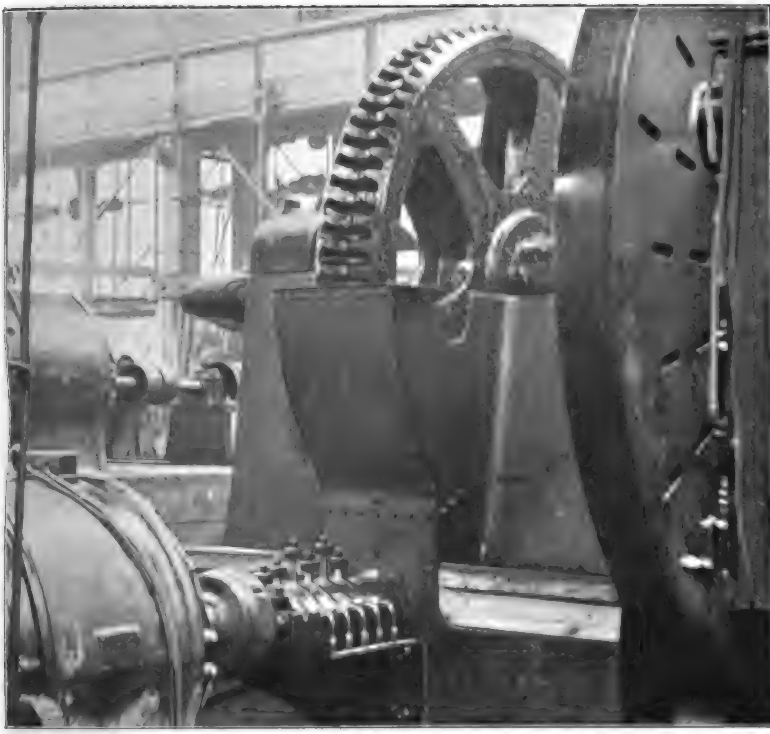


FIG. 1.

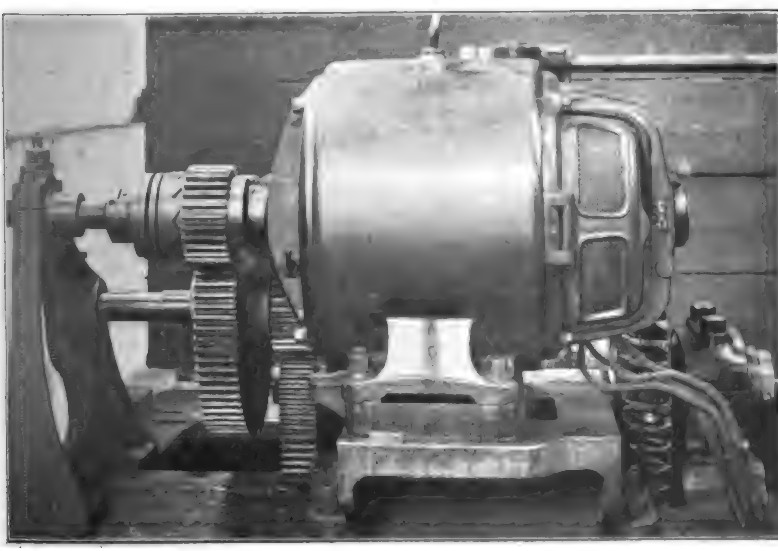


FIG. 2

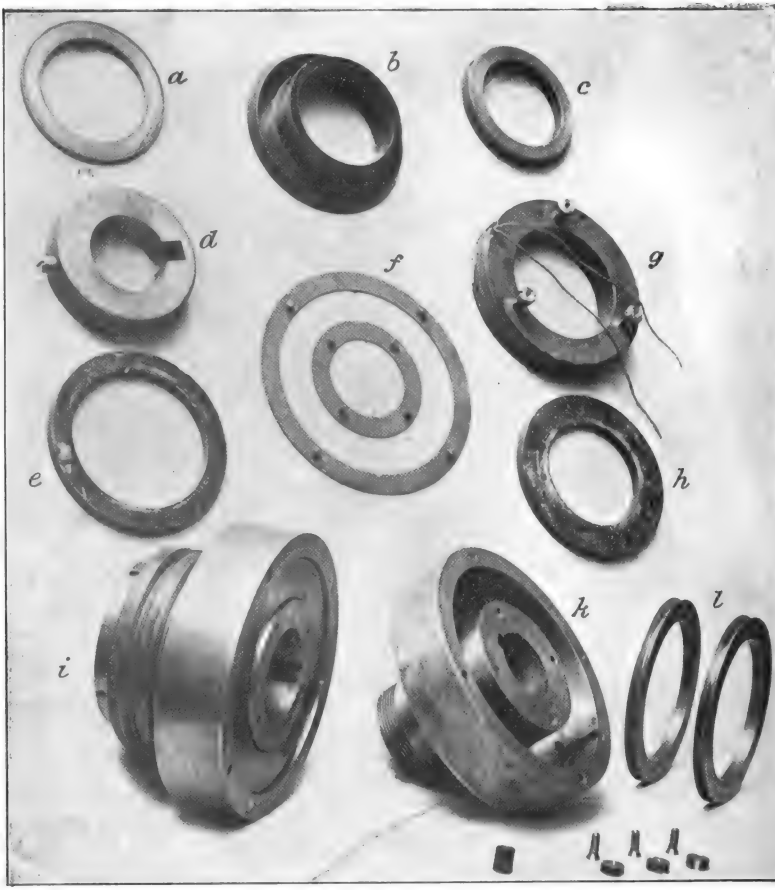


FIG 4

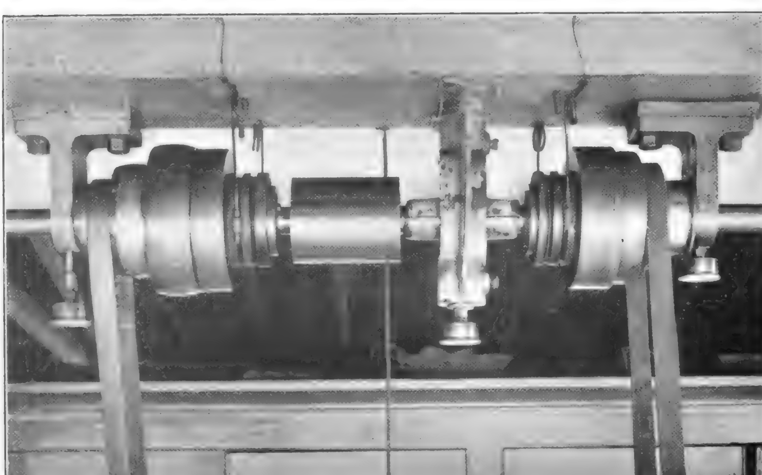


FIG. 5.

manufacture of guns ranging from 3 cwt. up to 60 tons or even more, and also in the manufacture of the breech mechanisms and other adjuncts and appurtenances of the guns themselves. This work necessitates a very large range of machine tools, from boring machines 50 yards in length, and lathes of 100 feet bed, down to the smallest milling machines and lathes. There is therefore plenty of scope and opportunity for the employment of different descriptions of electrical drives.

Although there were previously several instances where in the Factory electro-motors had been substituted for steam engines, it was only in 1900 that I converted the first of two large boring machines to a direct electric drive by means of a variable speed Schuckert 4-pole motor of 25 B.H.P. (Fig. 1). The variation of speed was obtained by the now well-known method of varying the excitation of the fields, and the ratio in this case was 1 to 3·5 or so, giving speeds of from 250 to 880 r.p.m., which is amply sufficient range, without any further gear, for the work that is put into these machines.

The machines themselves are of the simplest possible description The headstock which revolves the work carries between its bearings a large worm wheel (Fig. 1), which is driven by a worm shaft forming a continuation of that of the motor, but connected to it by a flexible coupling; the thrust of the worm shaft, which in such large machines is very considerable, amounting to tons in some cases, is taken by a thrust bearing of marine type, and through this the cutting lubricant passes on its way to the boring bar; this is only a precautionary measure, but, nevertheless, a necessary one, as not only is it very important that the machines should not stop during a boring operation, but also, as they have to run from early on Monday morning till late on the Saturday night, and are only stopped for shifting or adjusting the work or tools, it is imperative that any trouble that could arise from a heated bearing should be guarded against; and I am happy to say that so far there has not been a single machine stopped from this cause. They run absolutely silently and without jar or vibration; indeed, in this respect the worm and worm wheel, together with the electro-motor drive, is ideal; and even if it have the defect that it is slightly less economical than spur gear, this loss is more than compensated for by the extra accuracy of the work done and the freedom from breakage of tools. It would be impossible in a spur-gear driven machine, I believe, to fine bore a hole 12 in. to 20 in. in diameter and up to 50 ft. in length without a variation of 0·004 in. in diameter, which is what these boring machines are called upon to do, and do to perfection, daily.

The feed of the boring bar in the machines described is worked from the motor by means of a shaft, which connects it with change gear, similar to that of a lathe, at the other end of the bed, 150 ft. away. At this end there is also a 15-H.P. series motor, which can be mechanically coupled to the screw shaft moving the boring head and saddle, with the object of withdrawing or advancing one or both rapidly in either direction as required; in this case I have introduced

a slip coupling (Fig. 2), which in the event of an overload not only slips, but also draws attention to the fact by making a hideous noise; this is, I think, better in many ways than the overload release, and much more convenient, of course, than a fuse which has to be replaced. It may be interesting to you to know that the change to motor driving, and the improved control of the speed, enabled us to turn out at once more than double the former amount of work done per week. It was considered necessary at first to put the control of the speed in the hands of the foreman only, and for him to lock up the shunt regulator; this is now found to be an unnecessary precaution.

A later development of this method of driving is one whereby the driving shaft, just mentioned as running the whole length of the bed, is entirely done away with, and the one motor, now a variable-speed shunt

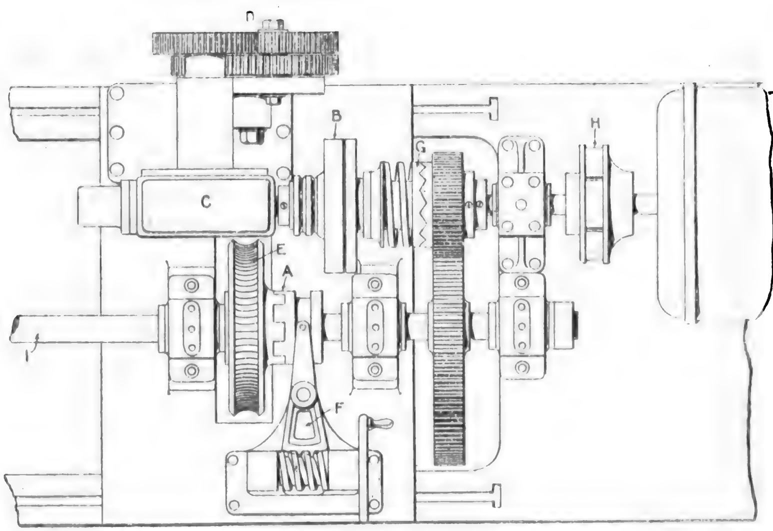


FIG. 3.

motor, does all the feeding of the boring bar, as well as the rapid advancement and withdrawal of it and the saddle, the latter weighing ten to twelve tons or more. How this is effected is shown in the diagram of this feed gear in Fig. 3.

The action of the gear is as follows:—The motor drives the shaft through a flexible coupling H. This shaft carries on it the magnetic clutch B, and beyond the clutch the worm C. It also carries on a sleeve a pinion, and the overload clutch G, and an armature. The worm gears into the worm wheel above it, from which the change gear D, similar to that of a screw-cutting lathe, and situate behind the worm wheel, drives a horizontal shaft on which another worm engages with a second worm wheel E. This latter can be clutched mechanically by the claw clutch A to the screw shaft I actuating the saddle.

The claw clutch A is moved by a hand-wheel in and out of position, and the lever F that moves carries a contact which only allows of the magnetic clutch B being in action when the claw clutch is disengaged. Thus normally the drive is through the worm wheels and the change gear, but when it is desired to move the saddle quickly the magnetic clutch is energised and the pinion on the motor shaft then drives a spur wheel which is keyed to the screw shaft I, the latter being thus driven direct. The feed can be varied practically to any extent required between the extreme limits by the combination of change gears and the varying speed of the motor. This gear is worked entirely from the main switchboard by which the man starts and stops and controls the speed of the headstock carrying the gun tube, and the switches are so interlocked electrically that it is impossible either to start the feed gear or to leave it running unless the main motor is running.

It will be seen that there is a magnetic clutch employed in connection with this gear, and as such clutches appear in a good many of the illustrations in the paper, I may as well describe it in more or less detail now.

This magnetic clutch is, of course, only a variety of a friction clutch, but it has advantages over the latter in that it can be used under conditions which would be impracticable, and in many instances impossible, for an ordinary friction clutch, owing to the fact that it can be as readily worked from a distance as from close at hand, whilst its action is quicker and more definite as to holding power, and it cannot possibly stick or seize.

As will be seen from the accompanying illustration (Fig. 4), the clutch consists of five essential parts, the slip rings *l*, for conveying the current to the coil *g*, the circular magnet *k*, the demagnetising rings, so-called, *f*, and the armature which is merely a plain disc of Swedish iron or a piece of high permeability steel. The remaining portions shown in the block are merely insulating rings, screws, and nut for building the parts into the complete clutch which is shown at *i*.

Two of the first clutches made over fifteen years ago are shown in Fig. 5, and these are still in perfect condition. I am at present only using two types of these clutches, one rated at 6 H.P. and the other at 25 H.P. at 300 r.p.m. Owing to the fact that the voltage of the supply circuit was 300, and also to the difficulty that there is in winding bobbins with a finer gauge of wire than No. 36 S.W.G., or 0·0076 in. diameter, it was not practicable to make a smaller clutch than the size named, which is only 7·5 in. in diameter; indeed, in this case even it is necessary to add 1,000 ohms resistance to that of the bobbin in order to reduce the current and prevent heating of the coil. 8,000 turns of wire are employed in either case, the sectional area of the bobbin being one square inch, and the total capacity of the bobbin being 15·7 cubic inches for the 6-H.P. and 32 cubic inches for the 25-H.P. clutch. 21 watts are absorbed in the magnetising coil of the 6-H.P. clutch and about 42 in the coil of the 25-H.P. clutch. This gives an efficiency of under 1·5 watts per H.P. in the case of the 6-H.P., which actually transmits 14·36 H.P. at 300 r.p.m.; the 25-H.P. clutch is still more efficient.

It will no doubt be readily seen that the diameter of the clutch has a more important effect upon the number of watts per H.P. transmitted than any other factor, and that it is quite feasible to transmit 1 H.P. for ¼ of a watt or even less. The original pattern of demagnetising ring was a complete disc which is simpler and not impracticable, but obviously some of the lines of force are uselessly diverted by it, and where high efficiency is desirable it should not be used. In the case of the clutch rated at 6 H.P. the H.P. transmitted at 300 revolutions is 12·73 with the complete disc as against 14·36 with the two rings—by perforating the disc with a ring of large holes concentric with the bobbin very nearly the same efficiency is obtainable as with the rings, namely, 14·32 H.P. These figures as regards H.P. transmitted were obtained with the surface of the clutches dry and free from oil, and it seems hardly necessary to point out that the H.P. which can be transmitted, if they are well oiled, is considerably reduced; it is therefore necessary to arrange in designing the mounting of these clutches that oil shall not by any possibility work itself between the acting surfaces. I have not found any great difficulty in this respect. Where it is impossible or undesirable to prevent the adhering surfaces from becoming oiled, then the clutch must be rated 50 per cent. lower, or else made larger in diameter to transmit the same power as when kept free from oil. Some 117 of these clutches are in daily work at the Gun Factory, and are applied to a variety of purposes, some of which are illustrated in this paper.

A view of the Gauge-room, Royal Gun Factory (Fig. 6), shows the method of driving the lathes and other machine tools which was introduced when the shop was remodelled some four or five years ago; I have also some views of existing shops in which the old system of driving is still employed, so that any one who wishes may be able to appreciate the simplicity of the later system, as compared with the former. In the new arrangement, the motor, a 15-H.P., is attached to the wall and drives the main shaft, which runs down the centre of the shop, by means of a belt at a point about midway in its length at a speed of 450 r.p.m.

There is none of the usual countershafting and its multiplicity of belts; instead there is one cone pulley over each machine, driving the machine in the usual manner with a belt. These cone pulleys are, however, not carried on the main shaft but on tubular bearings through which the main shaft passes quite clear, while the bearings themselves are supported on brackets; the pull of the belt thus does not come upon the shaft when the cone pulley is not running and the machine is idle; the cone pulley carries the armature of the clutch at one end of it, and against this end the electromagnet with its collecting rings is keyed or otherwise fixed to the shaft. The pins of the demagnetising rings enter holes in its face, and keep this part of the apparatus in position. Very slight longitudinal play in its bearing is given to the cone pulley, and a slight bias is given to the belt drive, so that the tendency of the pulley is to run from the magnet when the latter is de-energised. It is found that by

adopting this simple method no spring or other device is required to keep the surface from contact or rubbing when the clutch is not in action. The extent to which frictional losses are reduced can be imagined when it is explained that when the motor-driving belt is thrown off and there is no current on the clutches, the main shaft can be revolved between the fingers. The switches used to actuate the clutches (Fig. 6A) are of a selective type—that is, when the current is off, a pull at the switch rope puts it on, and a second pull cuts the current

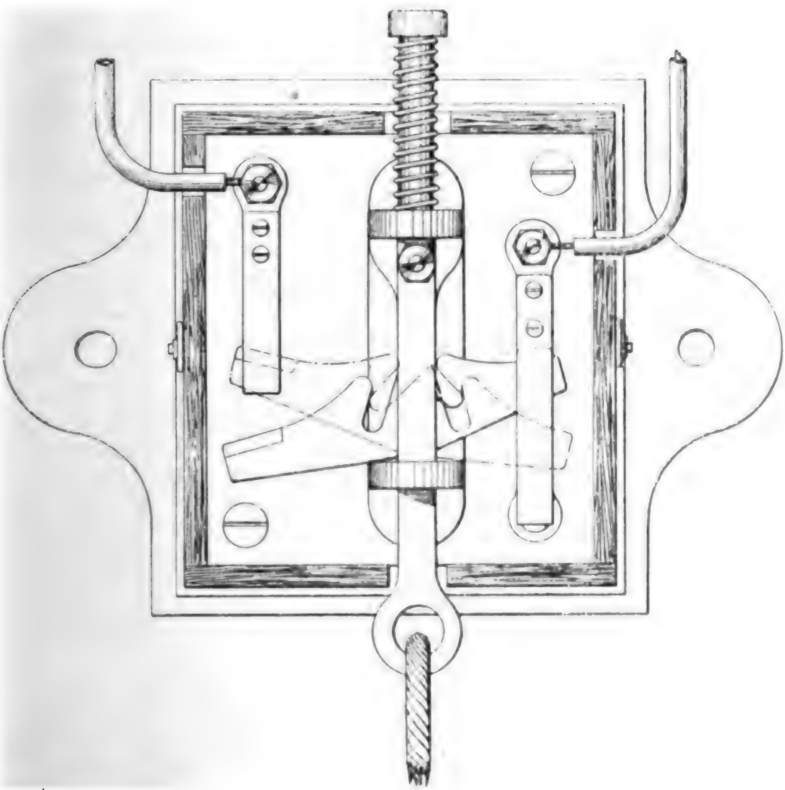


FIG. 6A.

off again; this appears from practical experience to be more convenient than the ordinary belt-shifting method in which two ropes are employed, one to put the power on and another one to cut it off. The base of the switch contains a condenser to render the extra current innocuous on breaking the circuit.

North-east Shop.—This is the most recent shop built in the Royal Gun Factory, and was designed with a view to electric driving. The work done in this shop is in connection with the smaller kinds of guns, and their mechanisms. It is a lofty building measuring 200 ft.

by 120 ft., with the now common saw-tooth roof, and divided into four bays running east and west. There is a gallery running all round it for fitters and bench work, offices, etc., and the large amount of glass makes it very light. Each bay is served by two 8-ton electric cranes. Altogether on the ground floor there are eighty-three machine-tools of which twenty-one are separately motor-driven, the other sixty-two being grouped and driven from one of the four main shafts which serve the same number of bays. The method of driving these main shafts 200 ft. long is by means of a 30-H.P. motor (Fig. 7) suspended from the girders and situated in the centre of the shaft, to each half of which it is coupled direct; the speed of the shaft is 250 r.p.m.

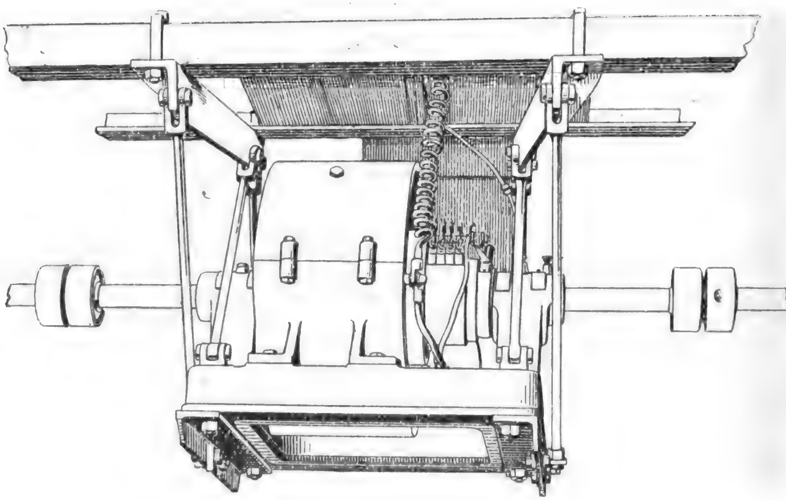


FIG. 7.

Grindery.—As in most modern workshops, it is the custom to grind the workmen's tools for them, and not to allow them to do this for themselves in the old-fashioned haphazard way on a grindstone. In the grindery devoted to this work some twelve Gisholt tool-grinders are continuously in use, and the problem to be solved was to drive them in the most economical and efficient manner. The grinders were arranged half on either side of the shop, and driven by belting (Fig. 8) from a shaft running at very nearly the same speed as the wheels, and coupled direct through a flexible coupling to a 6-H.P. shunt motor standing on a bracket fixed to the wall. The speed of the shaft is 1,400 r.p.m. Besides the tool-grinders there are also two small cutter-grinders, and in order to drive these latter, which are placed across the shop, it was necessary to have a shaft running at right angles to the other two. As the power required was small, this motion was transmitted by a friction disc and wheel, the wheel being

advanced so as to be in contact with the disc when it is required to rotate the shaft, which consists of a thin steel tube, and runs at 2,500 r.p.m. Some doubt was expressed as to the life of these high-speed shafts and bearings when they were first erected, but as they have been working for the last three years with practically no wear, it is evident there is no need for apprehension that they will not last. The economy in transmission here is considerable, owing to there being none of the usual countershafting; it is not uncommon to see machines of this sort driven from a high-speed motor, which, from a small belt pulley on its own shaft, drives a large one on a countershaft, which again drives by means of another large pulley the small pulley of the grinder. The best wheels for use on these grinders for high-speed tool steel have been found to be carborundum ones. Carborundum, as we know, is itself electrically produced at Niagara Falls.

Rifling Machine.—The method of driving of a large rifling machine for 12-in. guns is shown in Fig. 9. The term "rifling," of course, is applied to the operation of cutting the grooves which run spirally along the bore of a gun. In order to do this, a bar carrying one or more tools to cut the grooves, is drawn through the gun, and turned as it is moving to give the required twist. The saddles which guide the bar are carried on a bed within which is the screw for actuating the bar; as this screw revolves in one direction or the other, so the bar is moved in or out of the gun—cutting is always done by pulling the bar through, not pushing it, and indeed I may remark that in boring operations it is always better to have the cutter bar in tension than in compression; the end of this screw is coupled to a shaft passing right through the gear-box and supported in the bearing shown on the left of it in the picture. This shaft carries two magnetic clutches (Fig. 9A), one on either side of the gear-box. The motor of 30-H.P. drives a pinion which is always in gear with the teeth of the large internally geared wheel and also with a small spur wheel, running on the same centre as the former, but of course in the opposite direction. A clutch on the left connects the screw shaft to this latter wheel, whereas the clutch on the right attaches it to the internally geared wheel. It will be obvious that the direction of rotation of the screw shaft will be different, according as one clutch is in action or the other, and owing to the different ratio of the gears a quick return motion when not cutting is obtained. The motor and the gears run continuously in one direction, and therefore there is only the momentum of the screw shaft and inertia of the screw and saddles with the rifling bar to overcome on reversal of its motion. The action of reversing is entirely automatic, and worked by the movement of the rifling bar saddle. This drive works very smoothly and well—it enables the rifling of a 12-in. gun to be carried out in forty hours, six grooves being cut simultaneously, whereas only a few years ago the same operation, with one tool only cutting, took more than three weeks, working day and night; no less than twenty-six cuts have to be taken to finish each set of grooves, and I am able to show specimens of the shavings taken.

In contrast to this machine, I have an illustration of another driven

by the older method of crossed belts, which go through the usual shrieking performance whenever the drive is reversed. Within the last few weeks, however, this latter machine has been dismantled in order to lengthen it, and fit it with a driving gear similar to the one already described.

For lapping the bores of guns, an operation which has to be done in order to get the extreme uniformity of diameter that is necessary in

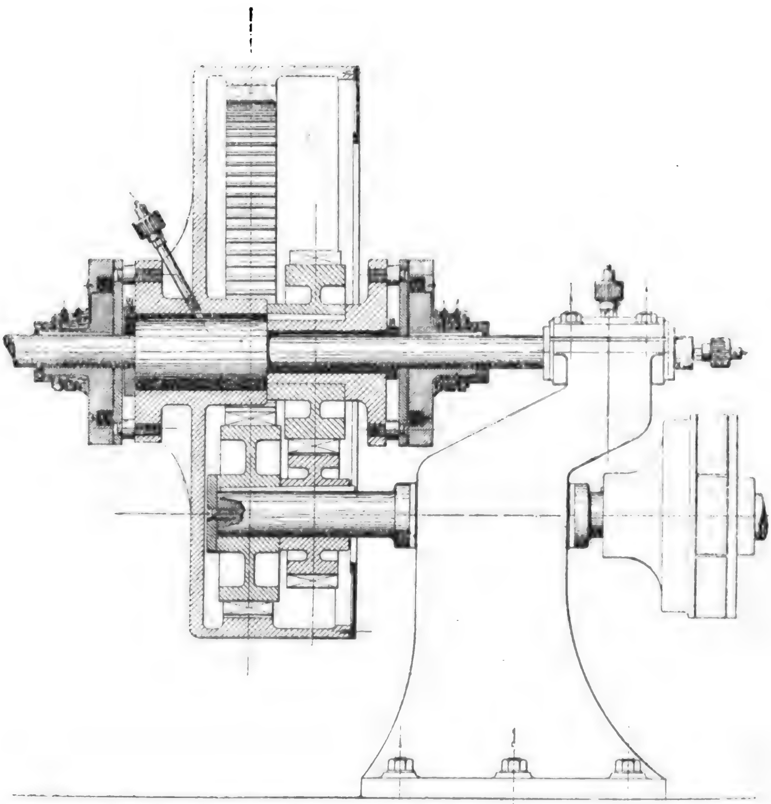


FIG. 9A.

the bore, both during manufacture and sometimes after the gun has been in use, there are three machines in the factory for dealing with various sizes of guns. Two of these were designed to be driven by separate motors, and the third was converted to an electric drive.

I may remind you that the operation of lapping is performed by means of an expansible lead-covered block or head charged with abrasive material, such as emery or corundum, which is attached to the end of a rapidly revolving shaft, and is capable, whilst revolving, of being moved from one portion of the bore to the other. A short and rapid to-and-fro motion should preferably be given to this head, so

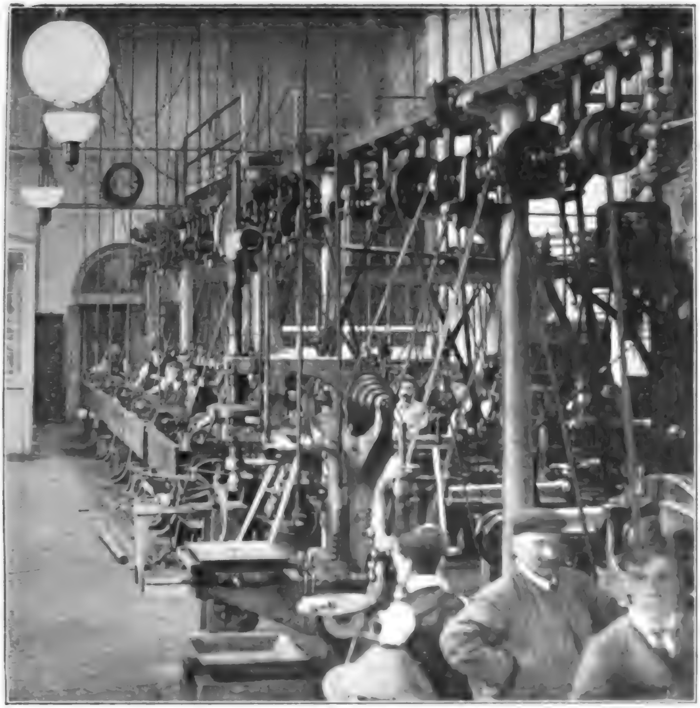


FIG. 6.

FIG. 8.

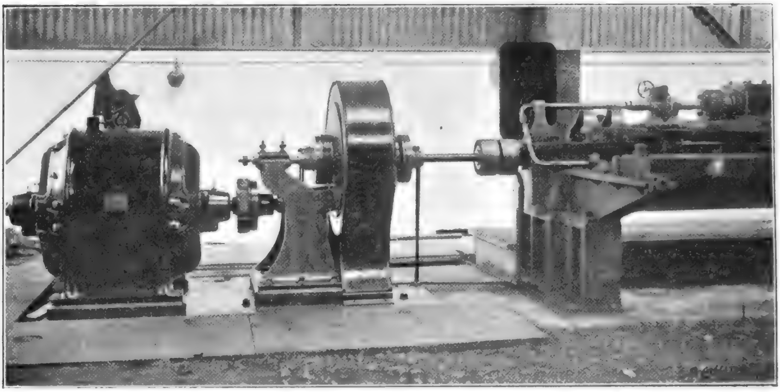


FIG. 9.

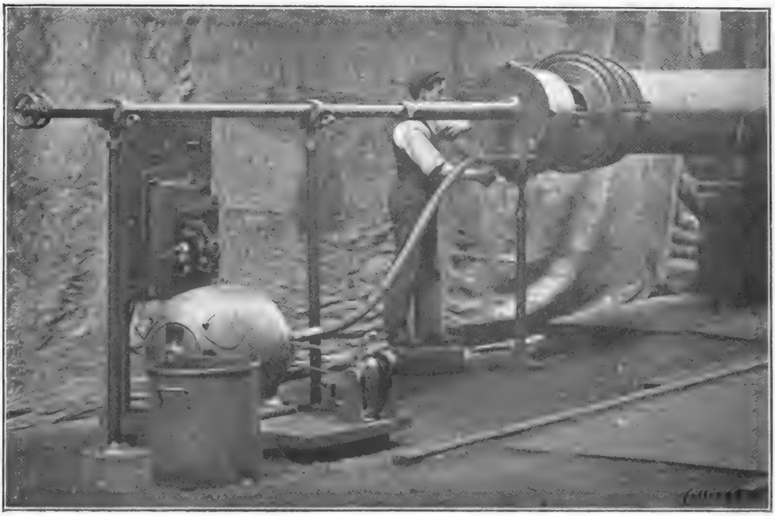


FIG. 11.

Fig. 13.

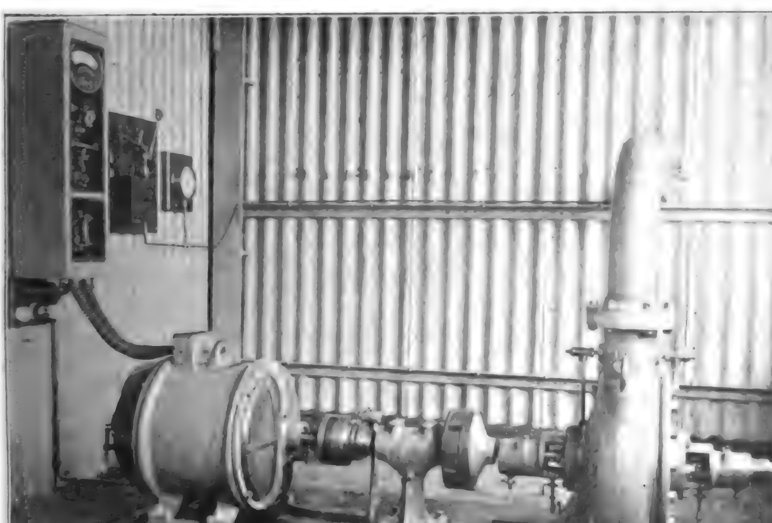


Fig. 16.

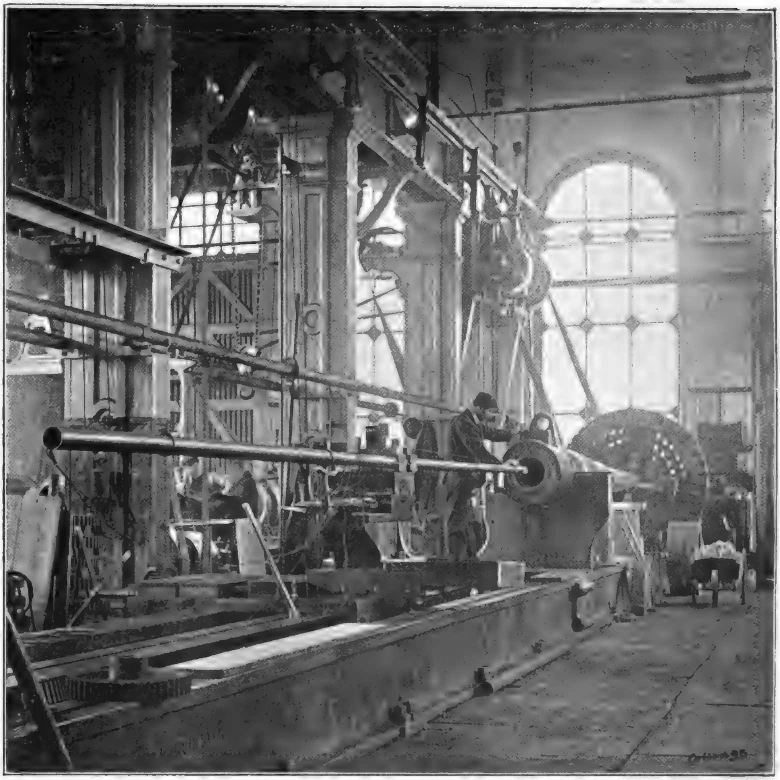


Fig. 17.

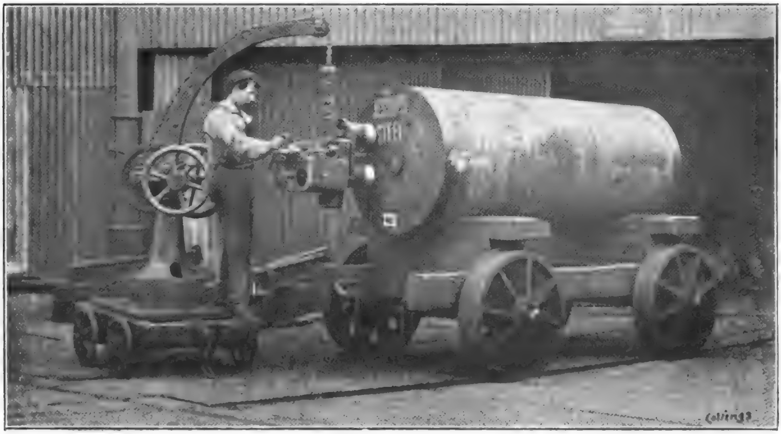


Fig. 18.

FIG. 19.

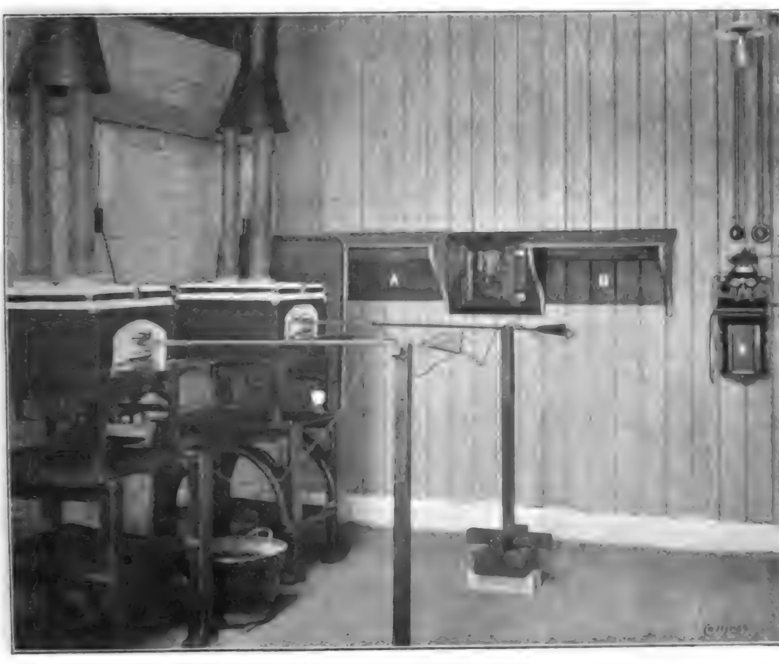


FIG. 20.

as to prevent the cutting of rings in the bore. The largest of the three machines is devoted to the larger guns, such as the 9·2-in. and the 12-in., and the motor is mounted above the saddle which carries the lapping shaft, and drives the latter by means of a short link belt. The large pulley is attached to the shaft by a feather sliding in a featherway cut the whole length of it, and in this manner rotates the lapping head. The saddle is traversed backwards and forwards along the bed by a screw extending the whole length of the bed and similar to the leading screw of a lathe. This screw, however, is stationary, and the traversing motion of the saddle is produced by means of a revolving nut, which is driven also by a linked belt and through reducing gear from a pulley carried on the other end of the motor shaft. The quick to-and-fro motion is given to the bar by the sleeve, which is clamped on to the bar between the two cheeks of the saddle and has cam grooves around it in which guide blocks fixed to the saddle are made to engage when required.

The liquid reverser, worked either automatically or by hand, is in front of the starting switch. The tightening of the belt is accomplished by sliding the motor across the saddle, and can be done by the hand-wheel when the machine is running.

The next size of machine is somewhat similar in design, but the motor is underneath the bed, and drives by gear entirely; the motor is not easily accessible, and is more liable to damage from emery and oil, and is mentioned more as an example of how not to do it. I must add, however, that it works very well. A diagram of the switch connections is shown in Fig. 10.

The smallest machine, situated in the north-east shop, is really a converted lathe, and is devoted to the smaller size of guns up to 4·7 in. I mention this as a practical example of the advantages possessed by magnetic clutches over the old system of reversing by a shifting belt. The machine, originally, had two shifting belts with loose pulleys and a fast pulley between them, on to which the belts were shifted in turn for reversing the direction of motion of the screw actuating the saddle. The central pulley was done away with, and magnetic clutches were applied to the other two; either one of these can be energised by a rocking switch actuated by hand or automatically. The result of this change was to enable the saddle screw to be run much quicker than before, the reducing gear between the pulleys and the screw being removed, and the latter driven direct, while the motion is reversed silently, instead of with a screeching of belts and clashing of gear. Altogether, four magnetic clutches are used with this machine, two on the main shaft, one to drive the headstock which rotates the gun, and another to drive the open and crossed belts, and then there are the two already described. This may seem a somewhat extravagant number to employ on one machine, but it is justified because the machine is not one that is in constant use, and the power absorbed by running three belts idle is very considerable, and quite a large figure when compared even with the total capital cost of the clutches, instead of the interest thereon and depreciation.

An illustration is also given of a portable electric lapping machine (Fig. 11) for use on board a ship or elsewhere. The machine itself, which embodies most of the features of the large machine, is here attached to the muzzle of the gun, and rotation is imparted from the motor to the machine by a flexible shaft (Fig. 12). The forward and backward feed of the lapping head is obtained by means of a friction clutch, controlled by a small lever, which regulates the movement of the nut through which the screw feed bar passes. If the nut is held still, the bar advances at the highest speed; if the nut is allowed to revolve at the same speed as the bar, no forward or backward movement takes

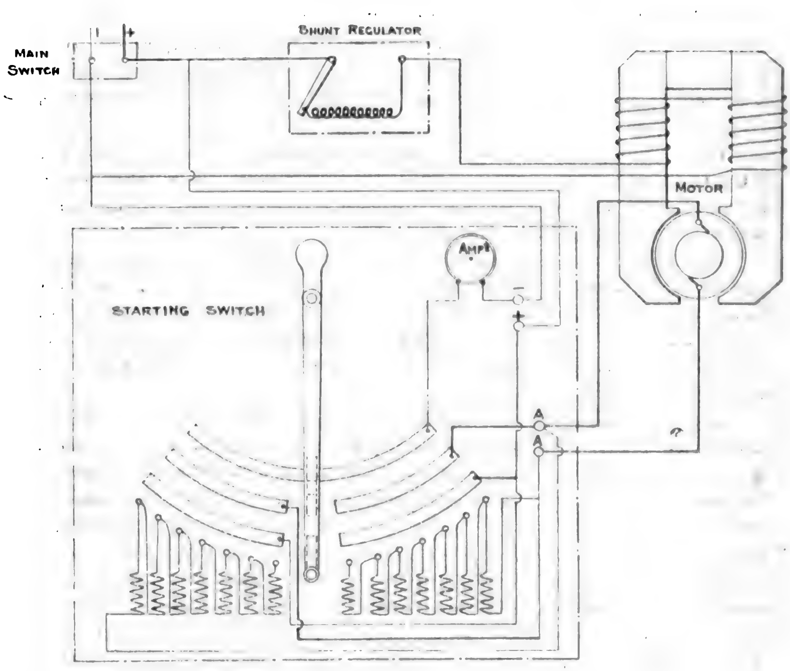


FIG. 10.

place; and if the nut is driven faster than the bar the motion of the latter is a backward one. In the first case the friction clutch is out and the nut held; in the second case the nut is free to revolve; and in the third case, the friction clutch being in, the nut is revolved at a higher speed than the bar, and so the bar is withdrawn. The power required for a lapping machine is always out of all proportion to the weight of metal removed, and in this case a motor of 6·5 H.P. is necessary.

We now pass to the electrically-driven planing machines, and I may here say that, so far as planing machines generally are concerned, I am in favour of cutting in both directions with two separate tools

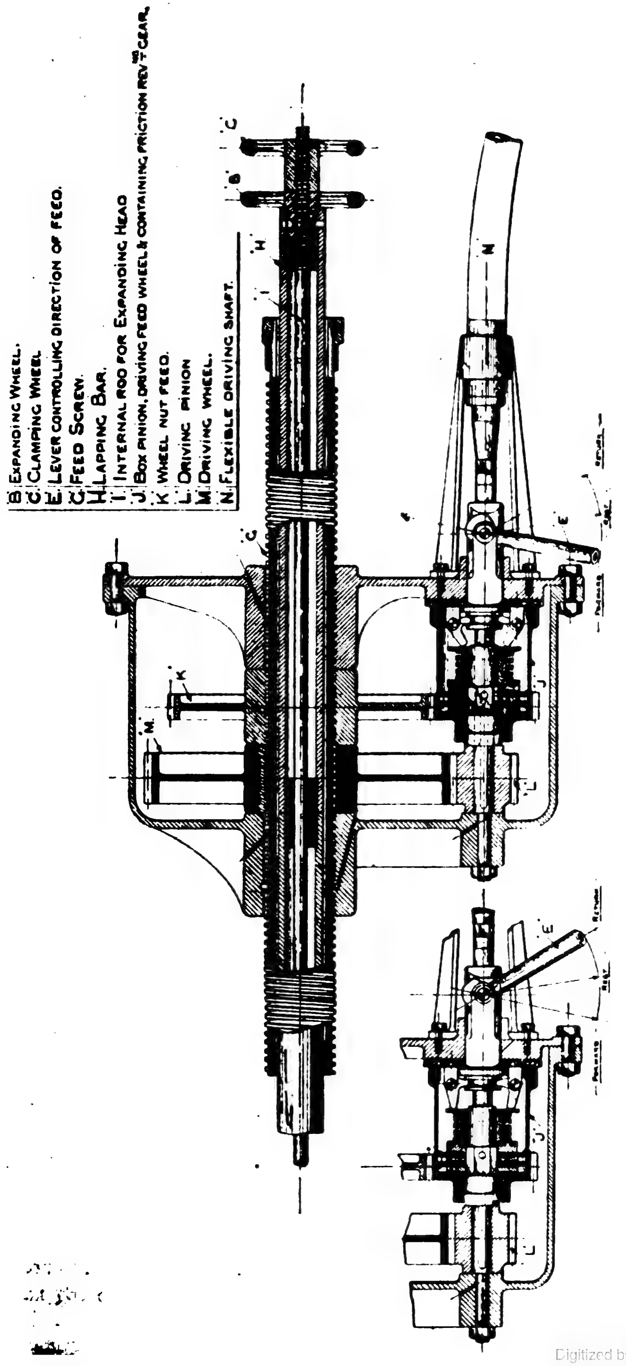

B. Expanding Wheel.
C. Clamping Wheel.
E. Lever controlling direction of feed.
G. Feed Screw.
H. Lapping Bar.
I. Internal rod for Expanding Head
J. Box pinion, driving feed wheel & containing friction rev'g gear.
K. Wheel nut feed.
L. Driving pinion.
M. Driving wheel.
N. Flexible driving shaft.

FIG. 12.

whenever and wherever it is possible, the economy in power, time, and labour being greater than having a quick return stroke, for it is obvious that however rapid the return stroke may be, time is lost, and no useful work is done. This will explain why the gear is so designed that the speed of the table in either direction is the same. In the case of planing machines, as in the case of the boring machines, I hold a strong brief for the screw drive as against the rack and pinion drive. The former undoubtedly does the better work. The planing machines are driven by a shunt-wound variable-speed motor, which runs continuously in one direction, and drives, by means of a bevel pinion, two bevel wheels revolving in opposite directions (Fig. 13); these two bevel wheels are concentric with the shaft which drives the screw of the planing machine, and are each furnished with a magnetic clutch, by which they can be attached to the shaft; the clutches are alternately energised by a rocking switch, actuated by adjustable tappets on the bed of the planer. The reversing action of these machines is very quick and silent. No check or change of speed is discernible in the motor, though of course the ammeter shows a momentary rise of about 25 per cent. on the reverse.

The special shaping machines used for interrupting the screw threads in the breech openings of guns seem very well adapted to driving in pairs, and this arrangement has therefore been adopted. The motor drives a countershaft placed above it, and the two machines are driven each by its own magnetic clutch, from this countershaft, by belting.

Mention may also be made of a heavy vertical milling machine, which was not originally designed for electric driving, but had to be converted. Though I am not in favour of very short belt drives when there is a difference of diameter between the driven and the driver, yet in this case it was almost the only arrangement possible, and, in point of fact, it has been very successful, the motor being supported on a Γ-shaped bracket attached to the upright of the machine, and to the portion of the frame carrying the driving-shaft.

Earlier in the paper I described a separate-feed arrangement for a large boring machine, and I now propose to illustrate a smaller one for high speed solid boring fitted with a somewhat similar arrangement. The machine itself has a mandrel, which is driven by a motor through a single reduction gear, for the reason that, although it would have been preferable to drive it direct from the motor shaft, this was not practicable, owing to the comparatively low speed required; the thrust of the boring tool (which is very considerable) is taken by a ball-bearing of large diameter forming the back of the face plate (Fig. 14), a device which has been very effective.

The feed gear is shown in Fig. 15. This, as in the other example, fulfils two functions, viz., that of the actual feed of the tool into the work, and also the quick withdrawal and advance of the same. In this instance two clutches are used, in conjunction with a claw clutch; and besides the safety arrangement provided to prevent the feed gear running after the headstock is stopped, or being started

before the other is in motion, there is also a switch worked by the lever actuating the claw clutch, which prevents the two clutches being operated simultaneously, or even the wrong one being operated. When the feed is in operation the motor is clutched to the first worm shaft and turns the first worm wheel, which in turn drives the worm of the second worm wheel, and the claw clutch being engaged, the screw is driven, and the saddle carrying the boring bar advanced. If now it is desired to withdraw the bar rapidly, the claw clutch is withdrawn, and the motion of the lever effecting this allows the second magnetic clutch to be rendered active, and this clutches the pinion to the motor shaft, and drives the spur wheel through the intermediate wheels. The speed of the carriage when feeding varies from 33 to 115 in. per hour, whilst the quick return is from 7 to 24 in. per minute, or nearly thirteen times faster.

In the south boring mill it used to be the custom, as elsewhere, to have each large boring machine supplied with cutting lubricant by a small and separate plunger pump, but a short time since it occurred to me that it would be preferable to have a constant and general supply from one source, and to do away with the small separate pumps. A high lift centrifugal pump, driven direct from a motor, appeared to be the most suitable pump for the purpose, and the pressure required being only 30 lbs. per sq. in., an old boiler was utilised as an accumulator and air vessel to maintain the pressure. The motor is coupled to the pump (Fig. 16) through a magnetic clutch and flexible coupling, and runs at 1,200 revolutions per minute, the clutch being used to connect or disconnect the two when the pressure falls below or rises above the amount that the automatic switch is set for. It is somewhat remarkable to see the extremely quick, and yet, as it must be, gradual, action of the clutch in starting the pump, which is of course started from rest with a full head—there being no appreciable delay or shock in so doing. This installation has proved so successful that a second set is being obtained, to enable the whole shop to be supplied. The motor of the second set will be so arranged that it will only be started when the first set cannot meet the requirements. The pump takes 14 E.H.P. and lifts 300 gallons per minute.

Once having introduced magnetic clutches into the workshop it is astonishing how quickly their applications seem to spread, and I propose to devote a few minutes to describing one or two special examples.

In the testing-room there is a small piece of apparatus which is used for compressing to a predetermined amount the copper cylinders employed in guns for ascertaining the pressures developed by the explosive; for instance, if a 15-ton per sq. in. pressure were anticipated, a copper pressed to 12 tons per sq. in. might be used. The pressure required is obtained by the weight of a column of mercury—the height of the column being varied by the displacement of the mercury by a piston of considerable area in a cylinder connected with the column. The piston is moved by a vertical screw, driven through gearing by an electro-motor, the copper cylinder being between two flat

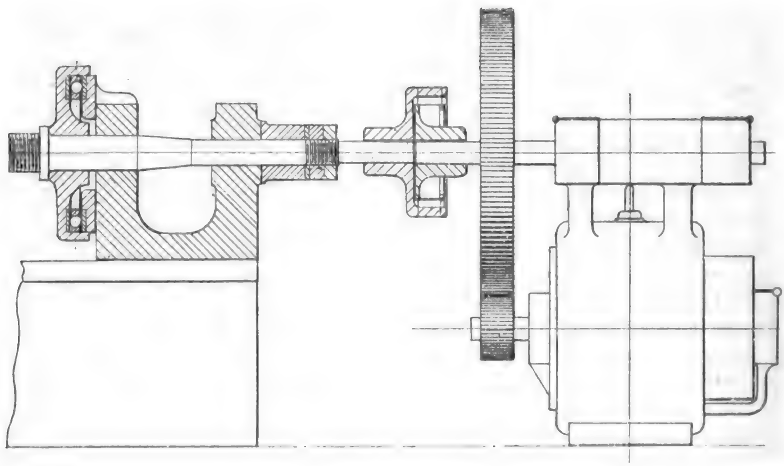


FIG. 14.

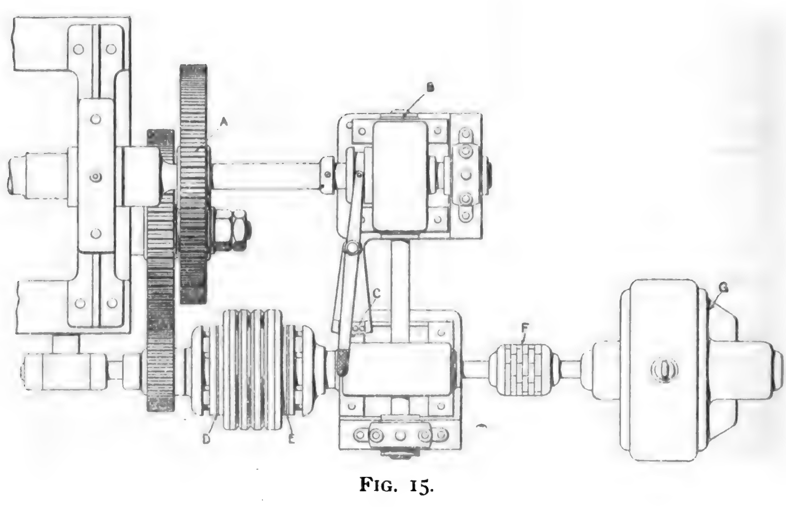


FIG. 15.

and hard steel surfaces interposed between the end of the screw and the piston. Means are provided for starting, stopping, and reversing the motor, but in order to get the practically instantaneous stoppage of the screw when the mercury has reached the correct height on the scale for the pressure required, a magnetic clutch is fitted as close to the screw as practicable, and is found to answer the purpose admirably, the switch controlling it being operated by the man's foot. The motor can then be stopped, reversed, clutched in, and the pressed copper removed and replaced by another and so on, the whole process taking longer to describe than to carry out in reality.

Electricity has been of assistance to us in enabling the amount of eccentricity of the bore of a gun which, as sometimes happens, has from one cause or another become bent, to be readily ascertained. You will, I am sure, appreciate the difficulty in first of all ascertaining, and secondly actually measuring, the want of truth in the bore of a gun 20 to 30 ft. from the breech end, which distance it may easily be, as the 12-in. gun is 45 ft. in length. The means adopted, however, are, thanks to electricity, quite simple (Fig. 17). A tapered steel tube, stayed and tied with a single gun wire so as to bring both ends of the tube to the same level, carries at one end a knife-edged contact wheel about 2 inches in diameter, this wheel being insulated from the tube, but connected to a flexible conductor passing down the interior of it to the other end of the tube which is fixed in the slide rest; a dead beat galvanometer and a couple of dry cells complete the equipment. When the wheel touches the metal of the gun, the circuit is completed through the galvanometer, which indicates accordingly. The movement of the slide rest, necessary to make contact, reveals the amount of eccentricity.

When any billet of steel arrives in the factory, the first thing to be done is to obtain a small quantity for chemical analysis. This is generally taken in the form of fine drillings from a point midway between the centre and exterior of the billet (Fig. 18) and at both ends. Until current was generally available throughout the factory, this was quite a lengthy operation, involving the loss of time taken to fix a ratchet brace, and then the time to drill the hole in order to obtain the shavings; by the aid of the electric drill, the time lost in fixing is eliminated entirely, and the drilling by power is quite a short operation.

I feel that my list of applications would not be complete if I omitted to refer to the use of the electro-magnet for lifting projectiles (Fig. 19), which was introduced by me many years ago when the 110-ton gun was in use. The cast-iron projectiles for proof were exceedingly awkward things to remove from the pile and sling for the crane to lift; this was made delightfully easy by substituting an electro-magnet for the sling. The magnet used consisted of one piece of mild steel of ⊓ section, and 10 in. in length, with a single coil wound round it longitudinally — the surface magnetised was 30 sq. in., and the maximum weight it had to support 1,800 lbs., the weight of the projectile of the 110-ton gun, though, as you will see, there was ample

power to spare. The weight of this magnet, complete with the shackles for attaching it to the crane hook, was under 56 lbs., and the electrical energy required for the maximum lifting power was 120 watts.

In any large gun factory, or indeed in any factory where large masses of steel are heated, forged, and tempered, or otherwise treated, it has long appeared to be absolutely essential that some means should be provided of measuring temperatures. This is most conveniently done by electrical means, and without going into the history of the matter and a description of the various instruments that are available for the purpose of measuring temperature electrically, I will merely say that, for our purpose, the measurement by means of the electro-motive force generated by a thermo couple has been found to be the best adapted.

The thermo junction we use is a platinum and iridio-platinum one, in conjunction with a modified form of D'Arsonval galvanometer to measure the electro-motive force which indicates the temperature. The instruments are fixed in various parts of the factory, and connected up to the re-heating, annealing, and tempering, etc., furnaces, as also to the lead baths (Fig. 20) for tempering steel specimens, in such a manner that the temperature of any one of them can be immediately ascertained by those in charge, and regulated accordingly; but this is not all. From each of these centres, so to speak, line wires are led to the metallurgical laboratory, where there is a standard recording instrument, and by this means not only can a continuous record be taken of any operation desired, but the individual instruments can be, and are, constantly checked to ensure accuracy and uniformity with the standard, for which purpose the points are connected by telephone. The standard itself is checked by the usual method of observing the freezing points of pure metals at various points of the scale. The zero of all the instrument scales is the temperature of boiling water, which, where steam is always available, as in our case, is readily arranged for, and is in itself a check on the accuracy of the instrument.

Automatic Water Clutch.—A difficulty arose in connection with the starting into motion of the heavy saddles of some double-ended boring lathes, by the 1½ H.P. motors that had been supplied with them, and after some trouble with burnt armatures and fuses the following arrangement was tried with complete success:—

The solid coupling was removed and a disc of cast iron, A, was keyed to the motor spindle B (Fig. 21). This disc carries a block of hard wood C on its face, the periphery being prepared with a semi-circular groove to carry an indiarubber tube D. This indiarubber tube is in halves, which are joined by a metal tube G let in across the diameter of the wooden disc. Outside the indiarubber tube is a split cast-iron ring E, similar to a piston ring, attached loosely to the iron disc so that it is free to expand. The tubes are then filled with water and the whole arrangement is fitted into a cupped disc F keyed to the shaft to be driven. When the motor is at rest the two portions of the clutch do not touch each other, but when the motor is started, and

as it gains speed, the water, acted on by centrifugal force, expands the rubber tube, and this in turn expands the split ring, which eventually rubs against and then grips and drives the other half of the clutch.

To sum up, there are at work at the present time in the Royal Gun Factory 134 motors of an aggregate rated horse-power of 1,903, whilst there are 61, either connected or ready to be connected, to the supply mains when current is available, of an aggregate rated power of 840 horse-power more. They consist of one motor of 100 H.P., one of 50 H.P., six of 40 H.P., thirty of 30 H.P., two of 25, eleven of 20, twenty-nine of 15 H.P., and thirty-nine of 10 H.P., the remainder

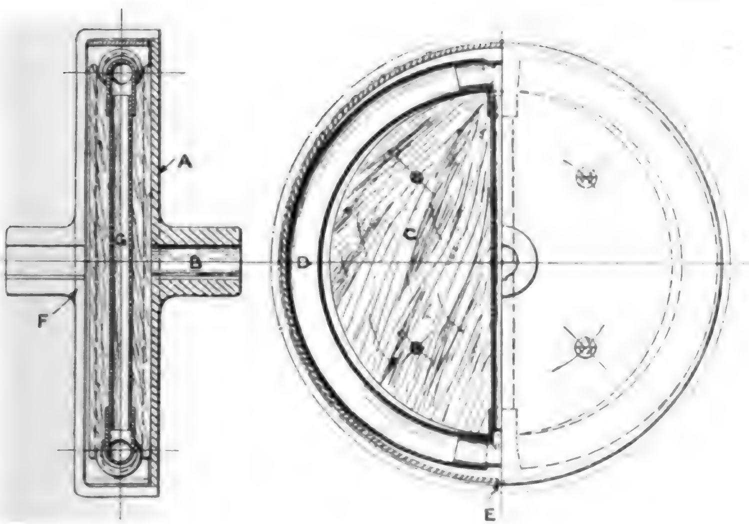


FIG. 21.

being under 10 H.P., and ranging down to 1 H.P. The largest motors, viz., 100, 50, and 40 H.P., are all connected to individual machines. The number of magnetic clutches in use is 117, thirty-one rated at 25 H.P. and eighty-six at 6 H.P. Of magnetic chucks and holders there are 16 in use, but fresh fields of application are continually being found for them, and their numbers are therefore constantly on the increase. Magnetic holders are of the greatest service in connection with surface grinding machines, and enable small steel work to be turned out with the greatest accuracy and rapidity. One instance may be given of the utility of the magnetic lathe chuck, and that is in turning obturator rings. These rings are made from extremely hard-tempered steel, so hard, indeed, that they can only be cut at a very low speed with specially hard tools, yet it is found that, in spite of the small surface area they afford for the magnetic attraction, and also of their somewhat low permeability, the magnetic chuck is the most effective method of holding them whilst being turned that we have

yet been able to devise. There is nothing very special in the construction of these magnetic devices; they are designed with a view of taking the standard size of bobbins used in the clutches, and by filling the air-gap with brass are so made that they cannot be damaged in any way by being used in oil or water.

It may be of interest, I feel, if I add a few data as regards the amount of material removed per E.H.P. per minute on various machines—the E.H.P. is the gross amount required not only to drive the motor and machine but also to do the work.

	B.H.P. of Motor.	No. of Tools.	Cut. Inches.	Feed. Inches.	Weight of Material removed per hour.	Lbs. per E.H.P. per Minute.
					Lbs.	
Fine boring machine	30	1	1·4	0·04	118·86	0·082
Rough boring machine	30	1	2·0	0·033	288·3	0·239
Experimental lathe	70	1	1·0	0·5	1652·0	0·38
" "	—	2 each	0·5	0·5	1052·0	0·417
" "	—	1	0·5	0·5	826·0	0·375
Medium boring machine, 5·75 hole from solid	15	—	—	—	132·6	0·142
Double-ended boring machine, 4-in. hole from solid ... ... One end only working	15	—	—	—	140·0 70·0	0·147 0·0956
Heavy single-spindle milling machine	15	—	—	—	14·0	0·049
Heavy double-spindle milling machine	15	—	—	—	85·0	0·109
Radial drill, $\frac{5}{8}$ in. high-speed twist drill	10	—	—	—	—	0·115
" $1\frac{1}{4}$ in. high-speed twist drill	—	—	—	—	—	0·180
" $\frac{5}{8}$ in. ordinary twist drill	—	—	—	—	—	0·04
" $1\frac{1}{4}$ in. ordinary twist drill	—	—	—	—	—	0·056

DISCUSSION.

Professor Ayrton.

Professor W. E. AYRTON: I am sure I am expressing the voice of the meeting when I say that we have all been delighted to hear such an interesting account of the use of electricity that Colonel Holden has introduced at Woolwich. We must congratulate him upon having replaced so many of the ordinary methods of driving machinery by driving them electrically. It is a very important matter in workshops to get more light than you can ordinarily obtain on account of the amount of counter-shafting and belts that obstruct it coming to the work that has to be done. This extension of driving electrically, as many of you know, is going on at a very rapid rate throughout the world. I was very much interested only a month or two ago in being taken over the workshops of the Central South African Railways at Pretoria, and to find that even so far away from centres of civilisation every tool—and there were a very large number—was driven electrically.

The question as to whether you should have a single motor for each tool or whether you should have tools attached to lines of shafting,

each line being driven with a single motor, is one which we would like to hear more about from Colonel Holden. At this particular workshop at Pretoria they had not arrived at any definite conclusion. As a rule there each tool was driven by a separate motor, but there were cases, as we saw in the gun factory at Woolwich, where they had a line of shafting driving several tools. I should be glad if, in his reply, Colonel Holden will tell us where he thinks the division should be drawn between separate motors and lines of shafting driven by a motor. There is another thing I should like to ask for some information upon, which very much interests me. We are all familiar with the new form, that is so much in use now in America, of having the lathe, or whatever the machine may be, made complete with the motor; that is to say, the motor is not an addition of any kind; it is not something screwed on to the floor, or to the ceiling, or put on a separate bracket, but the original casting of the lathe-bed, or whatever the tool may be, is made to receive the motor, so that the lathe, or tool, and the motor are made and sold as one piece of machinery. I am told there is an objection to that combination, namely, that it is very difficult with that arrangement to get perfectly true running of your tool, that there is a certain amount of vibration introduced by the process. I should like to hear from Colonel Holden whether he has found that objection to be serious. Professor Ayrton.

There is one other point which also interested me very much which was mentioned casually in the paper, namely, the way of stopping your machine. Of course, one very simple method of doing that with motors is to switch off the current; but apart from that he mentioned a plan where what is usually the loose pulley is carried by a sleeve going round the shaft, so that the loose pulley is not on the shaft at all. That is a plan which Mr. Mather and I introduced on trial at my laboratory some twenty odd years ago, and we found it to be so successful that it has been retained for more than one loose pulley ever since. The ordinary plan is that of allowing the belt to go on running after stopping the machine. There is another plan, and that is merely to shift the belt on to a pulley on the main shaft, a pulley which does not touch the main shaft. One of the advantages of that process is that everything connected with the tool is at rest, even the belt coming to it from the running shaft; there is absolutely no wear or tear, and no oil is required, because the wear and tear of the pulley, which is on the sleeve outside and not touching the main shaft, only occurs at the moment when the belt is being shifted from the stopped to the starting position. There is one objection, however, to that arrangement, arising from the belt being at rest when the tool is not being driven. You cannot, of course, easily shift a belt when a belt is at rest. It is quite easy to shift a running belt from one pulley to the other, but it is very difficult to shift a belt at rest from one pulley to the other; and the plan we adopted was that we simply moved the pulley which was on the collar surrounding the shaft a little sideways to bring it against the running portion of the shaft. That brings it into motion, and then you shift your belt in the ordinary way.

Professor Ayrton.

I was very much struck years ago with Colonel Holden's arrangement for lifting shot; and wholly without reference to this paper—in fact before I had received it—only a few days ago I was showing to my students, during a lecture, an old photograph that he sent me some years ago showing the magnet lifting the 1,800-lb. shot, and I pointed out what an enormously valuable tool Colonel Holden had introduced. That is a thing which has been, I think I may say, copied by the Americans. When I was over there a little while ago I found in more than one factory that what may be called Colonel Holden's method of moving masses of iron was in regular employment. An electro-magnet was brought down, the current was switched on, and the metal was lifted, taken away, and placed in its new position.

Mr. Russell.

Mr. S. A. Russell: With regard to the use of worm gear, to which Colonel Holden referred, and the smoothness of the running, we in our works at Silvertown have had a very considerable experience of worm gear and have found it very advantageous indeed. We have found that, although the initial cost of the worm gear is high to start with, the wear is so small, repairs are absolutely never required, and the smoothness of running is so great that the initial expense is thoroughly justified. We are using it for a variety of purposes, and in sizes from 150-H.P. down to about 2 H.P., and in all cases we are getting satisfactory results. The thrust block that we are using is perhaps a little different from what is generally used. It is a marine type of thrust block, but instead of having the collars on the shaft, in one piece with the shaft, we have separate collars. There is a feather on the shaft, and on these feathers are placed alternately rings as distance pieces and the discs that are going to form the collars of the thrust. We have adopted that plan because we are able to get a very much better surface on the hardened collar, and so very considerably reduce the wear. When the collars are part of the shaft it is not a very easy thing to get a thoroughly good surface on them, and to get it really absolutely hard. We are using collars of Pitho steel, and we find they take a most beautiful surface and are dead hard, while the wear is absolutely negligible.

There is one point in connection with the magnetic clutch that I would like to ask Colonel Holden's opinion upon. In connection with the centrifugal pump, he referred to the smoothness with which the magnetic clutch starts the pump. It is a thing I have not had any personal experience with beyond some unsuccessful experiments; and it was that very difficulty of getting a smooth starting of the machine which was my trouble. It appears to me that the magnetic clutch must be so sudden in action that the starting of the machine must be very sudden, and if, as in the case in which I was trying it, cotton threads had to be put in motion, there is a great difficulty about starting the machine up gradually enough to stop the breakage of the threads. Of course, the use to which Colonel Holden has put his magnetic clutches is possibly not quite so delicate as that of starting cotton threads, but his reference to that particular point of the smooth starting struck me as one I would like to get a little more information about.

Is there any appreciable slipping when the clutch is thrown into action, or do the clutch and armature come together and put the whole machine on almost at full speed? In the planer, for instance, when reversing, there must be a tremendous shock unless there is some little slipping; and if there is that little slipping, then I should have expected to hear there was more wear in the clutch than Colonel Holden speaks of as existing, seeing that he spoke of clutches which had been run continuously for fifteen years and were still in excellent condition. Mr. Russell.

Mr. A. W. Marshall: May I ask if Colonel Holden in his reply would kindly explain the function of the demagnetising ring of the clutches? It is not quite clear to me exactly what that is for. I think it would also be of interest if he would give us his opinion as to the merits of driving a planing machine by means of friction clutches for the running and reversing of the table. There was a large planing machine shown at the recent Electrical Exhibition at Olympia, which seemed to be working very well indeed, driven by means of a motor the armature of which reversed its rotation each time the table was reversed. It is not a question of single *versus* double cutting planers, but of reversing the heavy table and its load of work at the end of each stroke, a problem which has presented some difficulty with electric driving. Colonel Holden did not emphasise the wonderful working of the electrical cranes. At a recent visit to Woolwich Arsenal I had the pleasure of seeing many of the appliances which Colonel Holden has so very modestly described to-night. I was then much impressed with the rapid way in which the electrical cranes handled the work. It seems to me that a very great saving of time must result from their use, and I should be glad if Colonel Holden could make some further remarks on the subject. There was one point he did not mention in his paper, and that is, in adopting such a large system of electrical driving it is of great importance there should be no interruption in the supply of electricity; and perhaps a remark or two from Colonel Holden as to whether they have taken any special precautions to prevent the current being cut off from any of the shops at any time would be of interest, especially as he has said it is exceedingly important that the tools should not stop during some of the operations and that they have to run from one week end to another, or at any rate for a great length of time. Mr. Marshall.

Colonel Holden (*in reply*): In reply to Professor Ayrton, I am afraid I cannot draw any hard and fast lines, as I said in the opening paragraph of my paper, between the two systems of driving machines with electric motors—that is, driving them individually, and driving a number of them from a line-shaft. I think that is a matter which can only be decided by examining each particular case in detail. For instance, where you have a number of lathes, say 6-in. or 8-in. lathes, you might just as well drive them off a line-shaft, provided you take the precaution to reduce the frictional loss as much as possible. Supposing you drive ten or a dozen off a line-shaft, as I have done, I find that a 30-H.P. motor takes the load quite easily. They are not all working together, and therefore you are not asking the motor to do Colonel Holden.

Colonel Holden.

anything like, in many cases, its full load—at any rate, the motor never is called upon to do the whole of the work that would be theoretically required from a number of lathes like that. There is also this objection to driving tools individually, an objection which every one appreciates at once because it touches the pocket, that the cost of a number of small motors driving machines separately, with their switches and other arrangements, comes out very high compared with that of the single motor which will drive all the machines. As regards the building of the motor in with the machine, I think that, in a great many cases, it will work out all right. The cases in which I should employ it myself are ones where you can drive the spindle of the machine more or less direct from the motor. On p. 54 you will see an example of what I have done already in this direction. The picture (Fig. 14) is diagrammatic more or less of a high-speed boring lathe. It is a lathe with which we are able to bore a 3-in. hole in 40-ton steel from the solid at the rate of 5 feet an hour. That means to say that we must not lose any friction from the motor, and we must have means of taking up the enormous thrust produced when boring a hole at that rate. In this case I intended originally to put the motor direct on to the mandrel that carries the tube that is bored, and it was only the extra cost of a motor to run at the slow speed, which I think was 250 revolutions per minute, that made me adopt the plan that is shown in the diagram—that is, to use a motor with single reduction, and drive the mandrel itself through a flexible coupling, an arrangement which gets over the difficulty that Professor Ayrton spoke about, the vibration ; to take up the thrust due to the boring there is a very large ball-bearing, behind what becomes practically the face plate. Mr. Russell, I am glad to say, fully bore out what I myself think are the advantages of worm gear. I was very much interested to hear the way in which he had got over the difficulty of the thrust of the worm, because it is a difficulty, and I spoke of it as a difficulty which I myself had to get over in the first instance. I know what the difficulty of taking the thrust is. The end thrust of the worm shaft of one of these big machines amounts to something between three and four tons when the machine is doing its full work, and therefore it necessitates a fair amount of resistance and good lubrication to reduce the frictional losses to a small amount. A question was asked with regard to the smooth starting of the magnetic clutch. The answer to that is that it takes time to magnetise a magnet of that description, that the magnetisation is a gradual operation, and therefore there must be a slip. Though the slip may not be appreciable to the eye, and may not be appreciable to the ear, yet it must exist. It is essential it should exist in order that there should be smooth working and no jar on the driven and driving portions of the machines. As regards wear, the answer I would make is that the wear is light because the pressure per square inch is small. I think that is the conclusion we can come to, and the only one, because we know that in practice the wear is very small. I do not think I have had any demagnetising rings, as I call them, replaced at all due to wear. I think one was

destroyed on one occasion, nobody quite knew how, but it was not from wear. The action of the rings, which was referred to by Mr. Marshall, is this. I think they do not form such a complete magnetic circuit as the turned and faced surfaces of the magnet and the armature. They are stamped discs of sheet steel, and I think the two partial air-gaps that are formed on either side of them greatly assist in demagnetising the magnet after the current has been cut off. But whether that is so or not, I have found throughout that it is essential to use some device of that sort. The clutch will go on easily enough without the discs, but when you turn the current off it does not go off again. As regards the planing machines, and the comparison of the type that I am using with another one which has been mentioned, I do not want in any way to enter into any discussion as to the merits of individual systems. The only remark I would make is this, that when you are cutting in either direction with two separate tools, you are doing the utmost work that the machine is capable of if the machine is running at its proper speed, and as I said during my paper, it does not matter how fast you return the bed of the machine; if it is idle during that time, time is being lost because useful work is not being done. As regards the advantage or otherwise of reversing the motor, I cannot say, because I have not actually tried it; in the system that I am using I run the motor at full speed the whole time; it runs the same speed on the backward stroke as it does on the forward stroke, and the clutches merely determine which way the table should go. We have not found any difficulty about it, and therefore I suppose it is all right. As regards the interruption of the current, I do not myself supply electricity, I get it from a central station of which Colonel Bagnold, R.E., is in charge. We have ring mains and other mains, and of course we have a number of generating sets; since the introduction of electric driving in the gun factory I cannot remember any case in which the current has been cut off by any accident. Of course it has been cut off for one thing or another by arrangement, but this has never interfered with the work of the factory at all. Colonel Holden.

The PRESIDENT then proposed that the meeting accord a very hearty vote of thanks to Colonel Holden for his highly interesting paper, and the resolution was carried by acclamation. The President.

Proceedings of the Four Hundred and Thirty-first Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, December 7, 1905—Mr. JOHN GAVEY, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on November 23, 1905, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members—

Sam Handford.

From the class of Associates to that of Associate Members—

Joseph Percival Crowther.
Frederick Andrew FitzPayne.
Percy Good.
William Phillips.
Gilbert C. Vyle.
Frank Henry Whysall.

From the class of Students to that of Associate Members—

Henry Morrison Bremner.
Thomas Garnett.

Messrs. W. Henderson and R. E. Shawcross were appointed scrutineers for the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

Member.

Robert Henry Hammersley-Heenan.

Associate Members.

Charles Udall.
Harold Holmes Winston,

Donations to the *Library* were announced as having been received since the last meeting from Messrs. The Alliance Electrical Co., C. Bright, F.R.S.E., Prof. C. A. Carus-Wilson, The Electrician Publishing Co., The Engineering Standards Committee, Prof. J. A. Ewing, H. C. K. Fisher, K. Hedges, The Indian Telegraph Dept., W. P. Maycock, F. A. C. Perrine, Rentell & Co., Ltd., C. Rousset, The Scientific Publishing Co., Sir C. Todd, The Union Carbide Co., to whom the thanks of the meeting were duly accorded.

The PRESIDENT: I have a painful duty to perform in announcing to you the death of another of our old and honoured members. Sir Henry Fischer, who was well known in this country, and also on the Continent, for many years as the Controller of the London Telegraph Service, passed away at the end of last week after a somewhat painful illness, and I have to ask your permission to convey a vote of condolence to his family.

The motion was carried in silence.

The following paper was read and discussed; and the meeting adjourned at 9.30 p.m.

THE CITY OF LONDON WORKS OF THE CHARING CROSS, WEST END, AND CITY ELECTRICITY SUPPLY COMPANY, LIMITED.

By W. H. PATCHELL, Vice-President.

(*Paper read December* 7, 1905.)

In February, 1894, our late hon. member, Major-General Webber, C.B., presented a paper to the Institution on "Some Notes on the Electric Lighting of the City of London." The works which he described were increased from time to time, and held the monopoly for the supply of electricity within the City of London area until the granting of a Provisional Order, which was confirmed by Parliament in 1899, to the author's Company led to the construction of the works now to be described.

The prospect of the large demand for electricity which must be provided for in the City, and also the necessity of further generating plant in connection with the rapidly increasing West End supply of the Company, called for the provision of a plant on a somewhat unusual scale.

SITE OF GENERATING STATION.

Careful search had been made for a site near the City and the existing areas of supply, but the most favourable that could be procured was at Bow, about four miles from the Bank of England and close to the main line of the Great Eastern Railway. Here a plot of about eight acres was found with railway and water accommodation, although the latter was not sufficient for condensing purposes.

SYSTEM.

The question of system had to receive very careful consideration. The demand in the City was for direct-current, and the supply in the West End, which was to be augmented, was also direct-current, so that the supply to the consumer was naturally settled as direct-current.

When the plant was projected there was no large three-phase plant working in this country, and the relative merits of multi-phase and single-phase for generation and transmission had to be closely considered. Abroad a multi-phase system had in many instances taken the place of single-phase, particularly in connection with long-distance transmission, on account of its economy in line construction, as well as the facility it presented for working motors, and the choice in this instance fell on three-phase.

In considering the question of pressure, the author decided to take

the highest pressure that could be directly generated by the machines and used by the motors, as he was anxious to eliminate the complication of static transformers and to save the extra space and switchgear necessitated by them. 10,000 volts was the pressure chosen. At the time the only 10,000-volt systems in this country were in connection with the Deptford station of the London Electric Co.,* who were working single-phase with step-up and step-down transformers, and the Willesden station of the Metropolitan Electric Supply Co., who were working two-phase with step-up and step-down transformers.

The author has most pleasant recollections of discussions with contractors and specialists who tried to point out to him the great risk of working at 10,000 volts without transformers, and has been interested in watching subsequent developments. The Metropolitan Co. have put in all their subsequent plant for generating the voltage direct, and several large traction plants since laid out in this country are now either under construction or working at 10,000 to 11,000 volts, in each case without transformers.

The periodicity chosen was 50 complete cycles per second.

Generating Station.

The sizes of unit chosen for the generating plant were 800 k.w. and 1,600 k.w. The first portion of the plant ordered included two sets of each size.

The building was laid out for a boiler-room 75 ft. wide, with two rows of boilers facing each other; and an engine-room parallel to the boiler-room also 75 ft. wide, with 36 ft. 6 in. clear under the traveller hook.

The question of steam generated per square foot of ground space in the boiler-room imposes much more onerous conditions upon the designer than obtain when laying out the engine-room alongside; in fact, if the engine-room is laid out first it is frequently found that great difficulty is experienced in getting the necessary steam from the boiler-room parallel with it. This has led to double-decked boiler-houses, and also to the development of the Chicago design, in which there are several boiler-rooms at right angles to the engine-room, which has been developed at Carville, Newcastle, and brought before the Institution by Messrs. Merz and McLellan.†

As regards the type of plant to be adopted, it was felt that the load would grow so rapidly that no risk could be run with experiments, and the author therefore felt compelled to adopt such types of plant as could be seen in satisfactory work. The tenders for engines were submitted on the slow-speed and on the high-speed basis. The only large high-speed engine working at that time was a single representative of the Willans type in the Paris Exhibition.

A consideration of the tenders led to the selection of Messrs. Belliss

* Mr. G. W. Partridge writes under date of Dec. 12, 1905, that they have been generating at Deptford since 1890 at a pressure of 10,000 volts direct from the machines.

† "Power Station Design," *Journal of Institution of Electrical Engineers*, vol. 33.

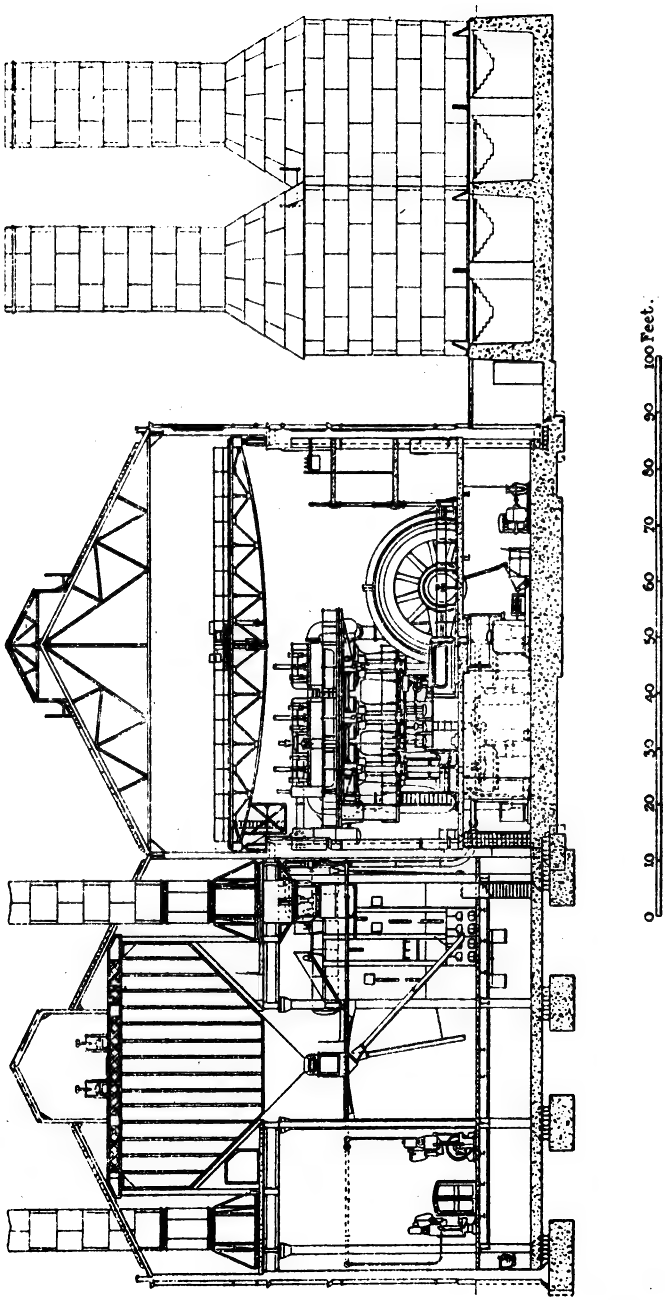


FIG. 2.—Bow Generating Station. Cross Section.

& Morcom's high-speed vertical engines for the 800-kilowatt machines, and Messrs. Sulzer Bros.'s horizontal slow-speed engines for the 1,600-kilowatt machines. These engines would lay out well on 35 ft. centres; boiler-room considerations, however, led to the adoption of 37 ft. 6 in. centres. Figures 1 and 2 are plan and sectional elevation of the station respectively. The existing building is 300 ft. long, and

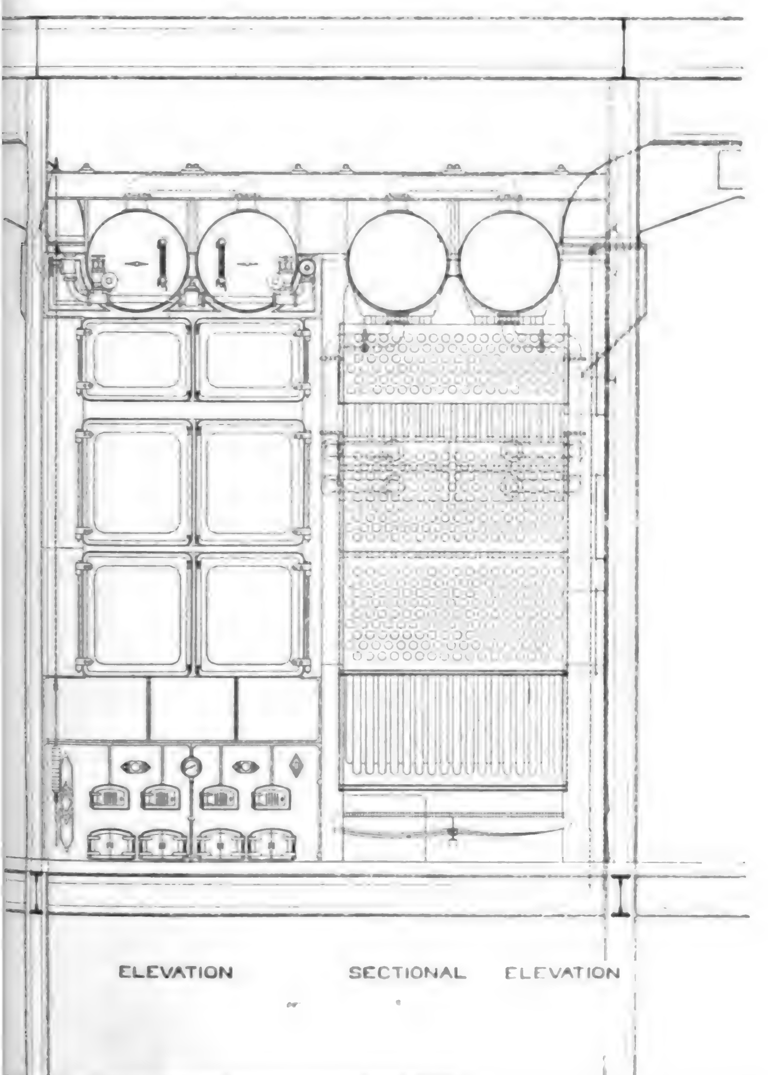


Fig. 3.—Hornsby's Horizontal Boiler.

the site is sufficient for the extension of it to 500 ft., and the provision of a similar building alongside.

Boiler-house.

The boilers adopted were of two sizes, both made by Messrs. Richard Hornsby & Sons, Ltd., Grantham. The smaller size had

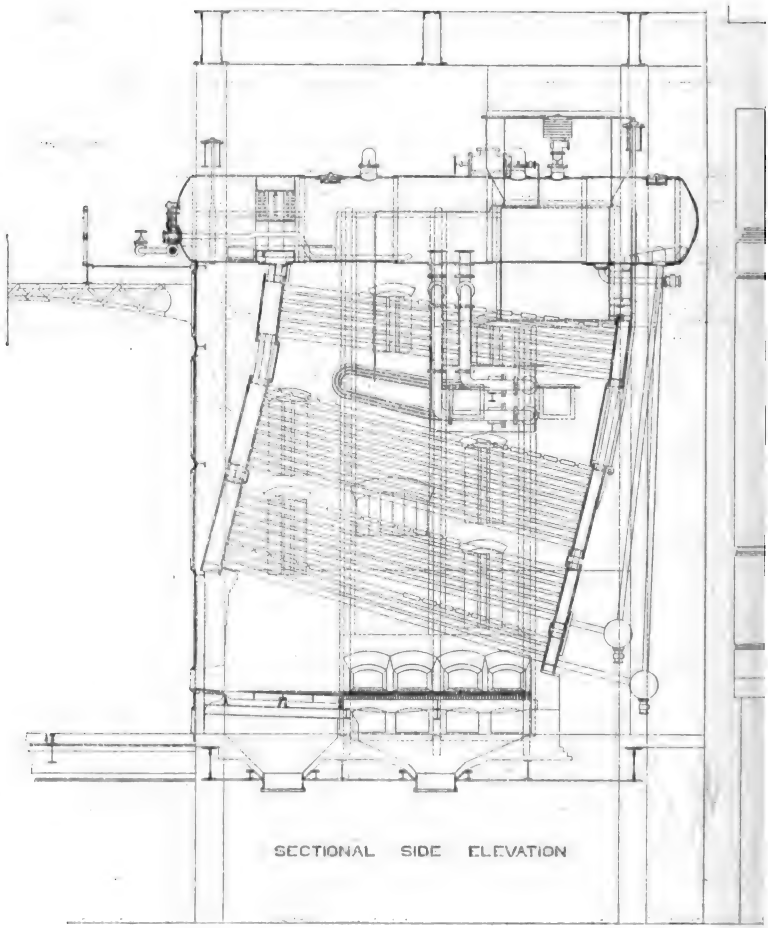


Fig. 4.—Hornsby's Horizontal Boiler with McPhail and Simpson's Superheater

already been in successful operation at the Charing Cross Company's Lambeth Works for some years; the larger size was specially built for this work.

Figs. 3 and 4 are front elevation and sectional elevations of the larger horizontal boilers, which are set in pairs.

There is one pair only of the smaller boilers, which were put in at the end of the room for light loads; these are fired in the usual way from the front only.

A novelty was introduced in the case of the larger boilers, where a grate was arranged in the ordinary way at the front and another at right angles to it, which could be fired from the side. These second grates have proved to be of enormous benefit when sudden fog or a thunderstorm has called for an extra supply of steam at very short notice. The ashpits for the two grates are quite separate, and are provided with the usual doors. At times of light load the boilers are fired from the front only, and the doors in connection with the side grates are all closed. A little dust falls on the bars at the back which are not otherwise protected, but do not suffer from the high temperature to which they are exposed. As soon as the demand arises coal is thrown on to the side grates, the ashpit doors opened, and the extra fires are got away with surprising rapidity. The large heating surface in proportion to the grate worked at light loads is an advantage, and the large size of boiler adopted gives much less radiating surface per square foot of heating surface than in the small sizes usually adopted.

Notice is also called to the special down-comers with mud-drum and header for the bottom rows of tubes immediately over the fire.

As mentioned above, the boiler-house was laid out for two rows of boilers in view of the larger engine units to be put in later. One row suffices to supply steam to the horizontal engines, which leaves the space opposite them available for lavatories, office, workshop, and pump-room.

Each boiler is provided with its own superheater of the McPhail & Simpsons' type, which was described by the author in his paper on Steam Superheating before the Institution of Mechanical Engineers, 1896 (p. 142). In the small boilers they are fixed immediately under the drum, in accordance with the practice originated by Messrs. McPhail in 1893, but in the larger boilers it was recognised that in this position the gases would be so low in temperature that the amount of heating surface to get the desired effect would have to be abnormally large. They were therefore put in about two-thirds of the way up the boiler, as will be seen on reference to Fig. 4.

The author has always been an advocate of large boiler units, both on the grounds of economy and convenience, and considers the horizontal type boiler, Figs. 3 and 4, about the limit in size for that type.

The development of Messrs. Hornsby's "Upright" type, however, presented further possibilities, which he gladly availed himself of. Last year a pair of these boilers were added, as shown in Figs. 5 and 6; they are erected as one steam unit, and the author believes that they form the largest steam-producing unit in existence.

The type of setting to be adopted was very carefully considered. Owing to the difficulties likely to be experienced, due to the expansion of such large walls in brickwork, it was felt that even if they could be kept upright they would not be air-tight; a modification of the wrought-

iron casing used for marine boilers was therefore developed, free from the restrictions as to weight which are imposed on marine engineers.

The first design adopted was a composite one of brickwork in the hottest area, extending about 8 ft. up from the ground line. This has been changed in a later design to wrought-iron casing throughout. In the fire zone the fire-bricks are 12 in. thick, while higher up tiles of 6 in. in thickness are used, the brickwork being separated everywhere from the wrought-iron casing by 1 in. of magnesia.

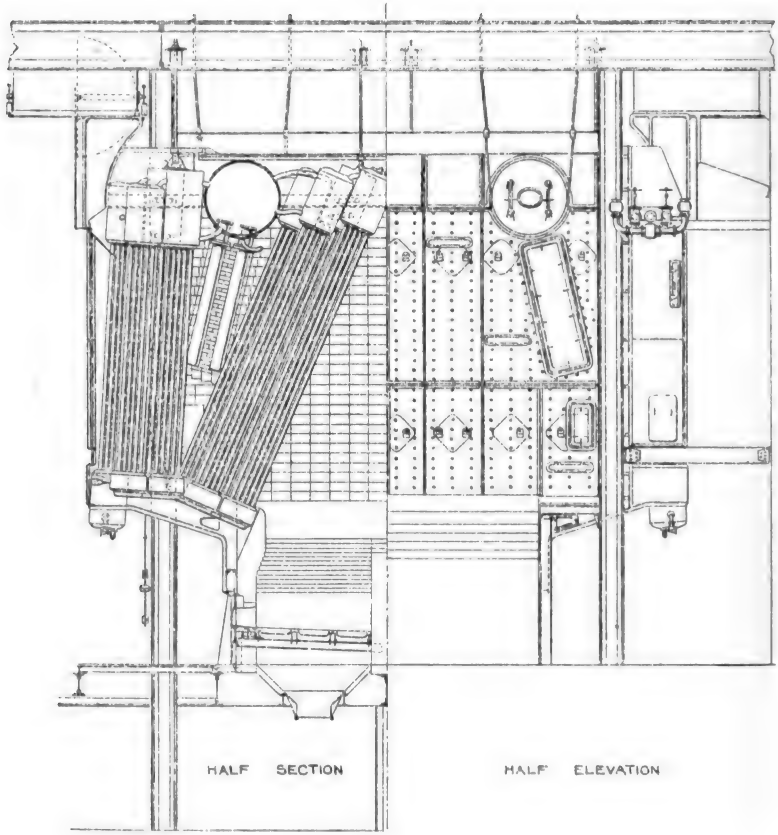


FIG. 5.—Hornsby's "Upright" Boiler with McPhail and Simpson's Superheater.

The brickwork between the grates, which is honeycombed and carried up about 6 ft., becomes incandescent during working, and its effect, combined with the ample combustion chamber, ensures a much more perfect combustion than is obtained in the horizontal type of boiler. Coal which might give heavy smoke when burned under the horizontal boilers can, with no more care taken in the hand-firing, be burned without smoke in the "Upright" boilers.

In the case of these boilers the ashpit is divided, so that only a part or the whole of the fire grate can be used as desired, with a similar benefit to that described above.

The upright tubes are a great improvement on the horizontal, both as regards external and internal cleanliness. The back sections act as

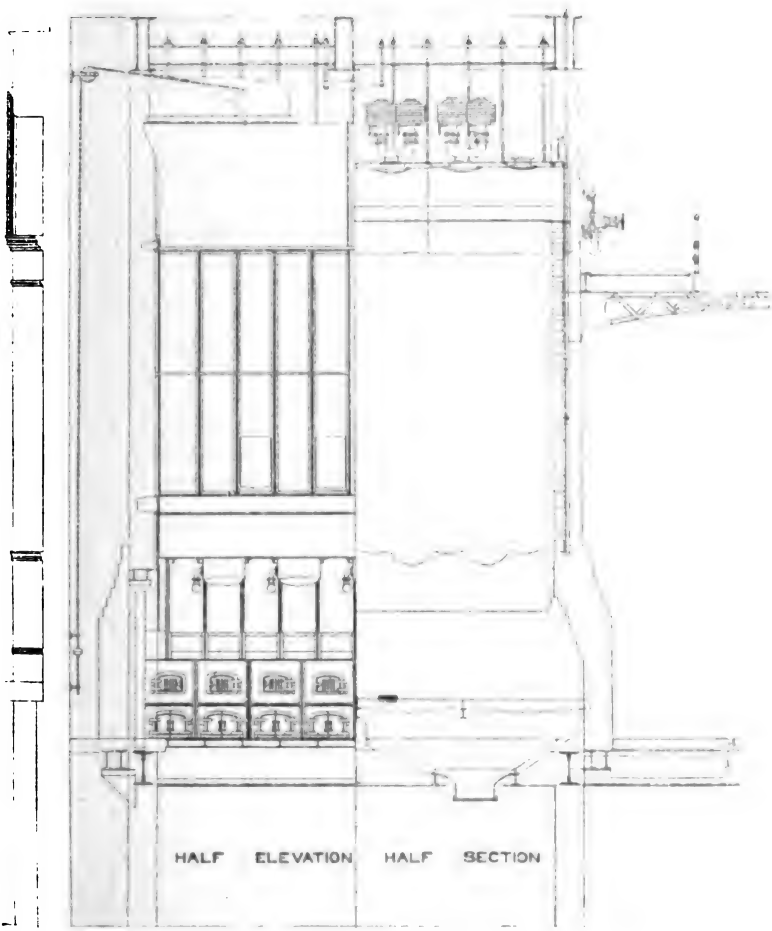


FIG. 6.—Hornsby's "Upright" Boiler.

water heaters or economisers with a definite circulation, any scale or sediment is deposited in them, and the front sections kept quite clean.

The pair of "Upright" boilers last erected as one steam unit have been steamed at the rate of 100,000 lbs. per hour, and so will easily provide steam under ordinary working conditions for a 4,000 kilowatt generating set. Superheaters were also included with these boilers, as

the author has long believed that a water-tube boiler without a superheater is incomplete.

Table I. gives the leading particulars of the three different sizes of boiler.

TABLE I.

PARTICULARS OF HORNSBY'S HORIZONTAL AND "UPRIGHT" BOILERS.

Description.	Horizontal.	Horizontal.	"Upright." *
Working pressure, lbs. per sq. in.	160	160	160
Over-all length of boiler	26 ft.	28 ft.	27 ft.
Over-all width of boiler	12 ft. 3 in.	12 ft. 9¾ in.	18 ft. 9 in.
Ground space occupied in sq. ft.	318·5	359	506
Height to centre of drum... ...	17 ft. 3 in.	27 ft. 5 in.	28 ft.
Water surface in drums in sq. ft.	202	244	268
Steam capacity above working level in cubic ft....	320	460	418
Water weight to working level in lbs.	46,930	74,597	78,440
Heating surface in sq. ft.... ...	4,590	8,100	10,850
Grate area in sq. ft.	62·5	125	168
Ratio H.S. to G.A.	73·44 to 1	65 to 1	64·5 to 1
H.S. per sq. ft. of ground space required per pair of boilers and stoking	11·7	12·6	21·45
Normal evaporation per hour, lbs.	12,000	24,000	33,000
Evaporation per sq. ft. H.S. per hour, lbs....	2·61	2·96	3·04
Superheater surface per boiler, sq. ft.	874	874	1,036

* Figures in this column refer to one boiler or one half the steam unit as erected.

The question of economisers was considered, but it was decided that, except at times of top load, the large heating surface available in the boilers would render the necessity for an economiser very doubtful; provision, however, was made for adding them at a later date should they prove to be desirable.

CHIMNEYS.

A large amount of ground space is usually taken up in boiler-houses by the foundations of the chimney; the author therefore decided to adopt steel chimneys supported by the steel main frame of the building and placed over the firing space between each pair of boilers. The gases from the adjacent boilers are led into the foot of the chimney by a short breeches piece, each leg of which is fitted with a regulator. It will be noted that this gives the gases an almost direct route from the grate to the top of the chimney, no brick flues are necessary, and no tortuous bends to throttle the draught; in fact, readings taken on many occasions have shown that the draught available over the grate is practically that theoretically due to the temperature and head.

Pump-room.

The water supply is derived from two 13″ Artesian wells on the premises, 400 feet deep, which each yield 15,000 to 20,000 gallons per hour as required. The method of pumping adopted is the air-lift system, and the water raised is discharged into a large reservoir in the basement below the pump-room. From this reservoir the water is pumped by slow-speed compound steam Woodeson pumps to a tank at the top of the building, from which it runs back by gravity through the water-heaters at the various engines to a tank over the pumps into which their exhaust steam is discharged and to which all the feed-pump suction-pipes are connected. There are also alternative suction-pipes direct into the reservoir in the basement. The feed-pumps are all slow-speed compound steam Woodeson type made by Messrs. Clarke, Chapman.

Generating Plant.

The first generating plant ordered consisted of two 800 k.w. sets and two 1,600 k.w. sets, but the demand arose so rapidly that before they were put to work two further 1,600 k.w. sets were ordered. Last year a 4,000 k.w. set was added, and a similar set has just been put to work.

The engines driving the 800 k.w. generators are three-cylinder triple-expansion, quick revolution, enclosed engines of Messrs. Belliss & Morcom's well-known type. They exhaust into jet condensers in the basement, the air and circulating pumps for which are driven by electric motors.

The engines driving the 1,600 k.w. generators are horizontal cross-compound engines by Messrs. Sulzer Bros., of Winterthur. In details they differ materially from the usual type of slow-speed engine, inasmuch as the connecting rods and cranks are enclosed, and the oil supply is continuous and under pressure.

The valves are of Messrs. Sulzer's latest 4-seated pattern. The pistons are provided with tail-rods, and are supported outside the cylinders by special bearings. The cranks are set at 108° instead of the more usual 90°, with the low-pressure crank leading. The exhaust steam from the low-pressure cylinder is divided in an oil separator and taken to two jet condensers, one on each side of the engine. These condensers stand on their air-pumps, which are driven from the high and low pressure crank pins respectively.

The engines driving the 4,000 k.w. generators are vertical 3-cylinder compound, with the high-pressure cylinder in the centre and a low-pressure on each side of it driving on to cranks which are equally divided. By this arrangement excessive weight or dimensions of any of the parts is avoided, and an even turning moment is obtained.

Figs. 7 and 8 show the general arrangement of the engine, and it will be noticed that here again the type approximates more closely than is usual in slow-speed sets to an "enclosed" high speed forced lubricated engine.

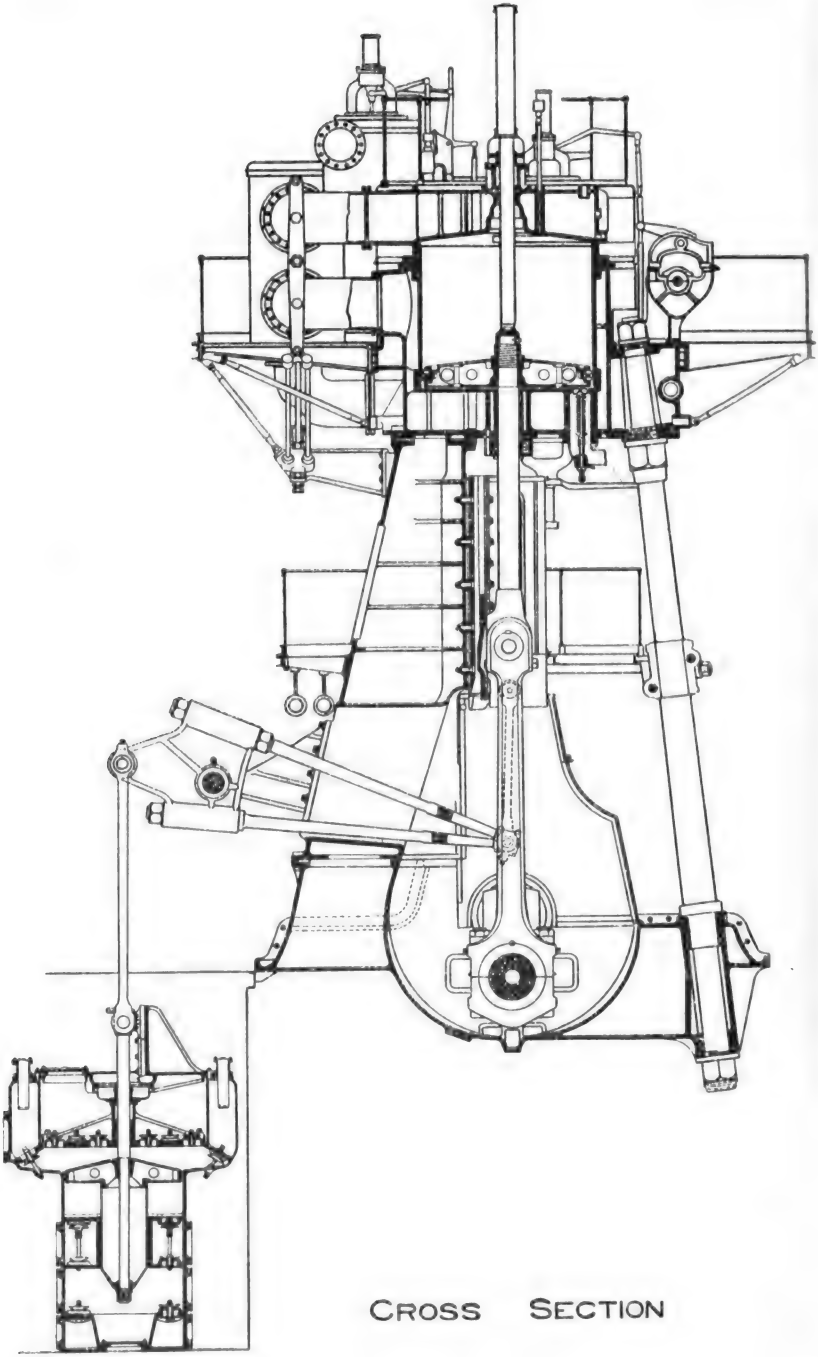


FIG. 8.—Sulzer's Vertical Engine.

The piston-rods, cross-heads, and connecting-rods are entirely enclosed to prevent splashing. The oil is supplied under pressure from a tank above the cylinders, and after running through the engine bed to a filter tank in the basement it is returned to the tank at the top by pumps and used over again.

The valves are of the 4-seated type, as used on the horizontal engines. Main and safety governors are both provided, and the latter in addition to automatically closing the main steam valve opens an air valve to break the vacuum. This arrangement can also be operated by a lever from the driver's stand, where all the hand wheels and levers necessary for working the engines are assembled.

The jet condensers are provided with separate air-pumps driven from the low-pressure cross-heads.

A special feature which shows clearly in Fig. 7, and has proved thoroughly satisfactory, is the adoption of feed-water heaters on all the engines inserted between the low-pressure cylinder and the jet condenser.

Condensing.

Although the Bow Back River suffices to bring freights of coal or machinery to the works, and affords an alternative route to the railway, the water supply was quite insufficient for condensing purposes. As economical working cannot be obtained without condensing, and as the space available was insufficient for cooling ponds, arrangements were made for the necessary cooling of the circulating water in towers.

Jet condensing has been adopted throughout, due to the trouble that the author previously experienced in keeping surface condensers clean enough to ensure a good vacuum with the temperatures available when working in connection with cooling towers.

As mentioned above, the Belliss engines are served by separate condensers driven electrically, while the Sulzer engines each have their own duplicate condensers and drive their own air-pumps.

The air-pumps deliver into steel hot wells, and from these hot wells the water is taken by centrifugal pumps, direct-coupled to motors, and delivered into the cooling towers. The vacuum obtained under normal working conditions is between 25 and 26 inches.

Cooling Towers.

The cooling towers have steel circular shells, to which considerable objection was made by some makers who had previously been accustomed to wooden shells for such plant. The steel type may not be so artistic, as it does not present such opportunities for decorative treatment as the timber, but the author considers that they are much more business-like from the engineering point of view. The standard unit of size adopted was for 25,000 lbs. of steam per hour on easy working.

Figs. 1 and 2 show the general arrangement of the towers, which

are 30 ft. in diameter, 38 ft. high to the base of the cone where the water is delivered into them, and 85 ft. high to the top of the chimney.

Exciter Sets.

A small continuous-current plant has been provided to supply the energy required for the generator fields, station lighting, and the various motors which drive the circulating pumps, coal cranes, travellers, etc.

The plant consisted of two of Messrs. Belliss & Morcom's 3-cylinder triple-expansion quick-revolution enclosed engines driving 300 k.w. Lahmeyer continuous-current 200-volt dynamos, and exhausting into the same condensers as the 800 k.w. sets. These are supplemented by

TABLE II.

Particulars of Engines.

Type of Engine.	Triple Vertical Belliss & Morcom, Ltd.	Triple Vertical Belliss & Morcom, Ltd.	Compound Horizontal Sulzer Bros.	Compound Vertical Sulzer Bros.
1. B.H.P. Normal ...	350	1120	2,500	6,000
2. Steam Pressure, lbs.	160	160	160	160
3. Diam. H.P. Cyl. in inches	11	19	$34\frac{3}{8}$	$50\frac{1}{4}$
4. Diam. M.P. Cyl. in inches	17	28	—	—
5. Diam. L.P. Cyl. in inches	24	43	61	2–$70\frac{7}{8}$
6. Stroke	12	20	$59\frac{1}{8}$	$51\frac{1}{4}$
7. Cyl. Ratio H.P. to L.P	1 to 4·75	1 to 5·12	1 to 3·15	1 to 4
8. Revs. per minute ...	365	230	83·3	83·3
9. Diam. Piston Rod in inches	$3\frac{1}{4}$	$4\frac{1}{2}$	$8\frac{1}{4}$	$9\frac{1}{4}$
10. Diam. Crankshaft Bearings in inches	$6\frac{1}{2}$	$9\frac{1}{2}$	$19\frac{1}{2}$	$24\frac{13}{16}$
11. Length Crankshaft Bearings in inches	15	24	$33\frac{7}{16}$	$35\frac{7}{16}$
12. Diam. Steam Pipe in inches ...	5	8	10	14
13. Diam. Exhaust Pipe in inches ...	10	18	2–20	2–26
14. Floor Space occupied by Engine in sq. ft.	72	229	1,128 including generator	540
15. Overall height of Engine above Floor Line ...	6′ $8\frac{1}{2}$″	16′ $10\frac{1}{2}$″	11′ 5″	33′ 4″
16. Weight Engine without Generator, in tons ...	14	$41\frac{1}{2}$	170	450

two 350 k.w. motor generators similar to those used in the City, as will be described later, and by a Hart storage battery.

Table II. gives the general dimensions and data for each type of engine.

Generators.

Probably the most striking feature in the generators is the elegance of design combined with solidity and stiffness of construction. In each size of machine the stator is of the box-girder type cast in two or four parts held together by flanges and bolts. The frame is of sufficient stiffness to keep its shape without either radial arms from a bossed centre or stay bolts, such as were lately fashionable in some types of machines. Such a construction saves weight, and if it were possible to use it in a rotor it would be excellent, but unfortunately the rotor must have weight to give the necessary steady turning, and the stator must be of such construction and so stiff that it will keep its shape under the strains which arise in working due to magnetic pull and from heating.

The stator-frames are all bored out in the vertical position in which they will subsequently stand when permanently erected.

The winding is in mica tubes embedded in slots which are nearly closed. Crossings of the wires are as far as possible avoided, and where the coils leave the iron core they are carefully wound over templates and covered over with insulating tape to prevent breakdown between adjacent coils or between coils and the frames. The coils are further protected from accidental contact by a strong perforated cover, which also enhances the appearance of the machine.

If some of the theories which have been advanced in connection with Mr. J. S. Highfield's discovery of nitric acid in high-tension machines (vide *The Electrician*, vol. 54, p. 573) are correct, evidences of such acid might reasonably be expected in these machines, and it is interesting to note that even careful dissection and examination has revealed no signs of it. It appears to the author, therefore, that probably the acid is due to impurity of the insulating materials rather than to the destruction of pure material by ozone.

The rotors or magnet wheels, which also serve the purpose of fly-wheels, are built up in one or four parts, and are held together by means of bolts and shrunk rings. Such rings are not only used at the hubs, but also at each side of the joints on the rim.

The machines are provided with two sets of spokes or arms. The wrought-iron poles are solid, of circular shape, and bolted on to the wheels in such a manner that they may be dismantled at any time without altering the position of the stator.

No difficulty whatever has been experienced in paralleling the 800 k.w. machines driven by high-speed engines with the larger machines driven by slow-speed engines; any or all of the machines will run in parallel in a way that reflects the greatest credit upon the respective engine and machine builders, and gives confidence to the men who operate them.

Figures 9, 10, 11, are reduced from working drawings of the 1,600 k.w. and 4,000 k.w. machines respectively.

The drawings of the 4,000 k.w. machine are especially interesting, as

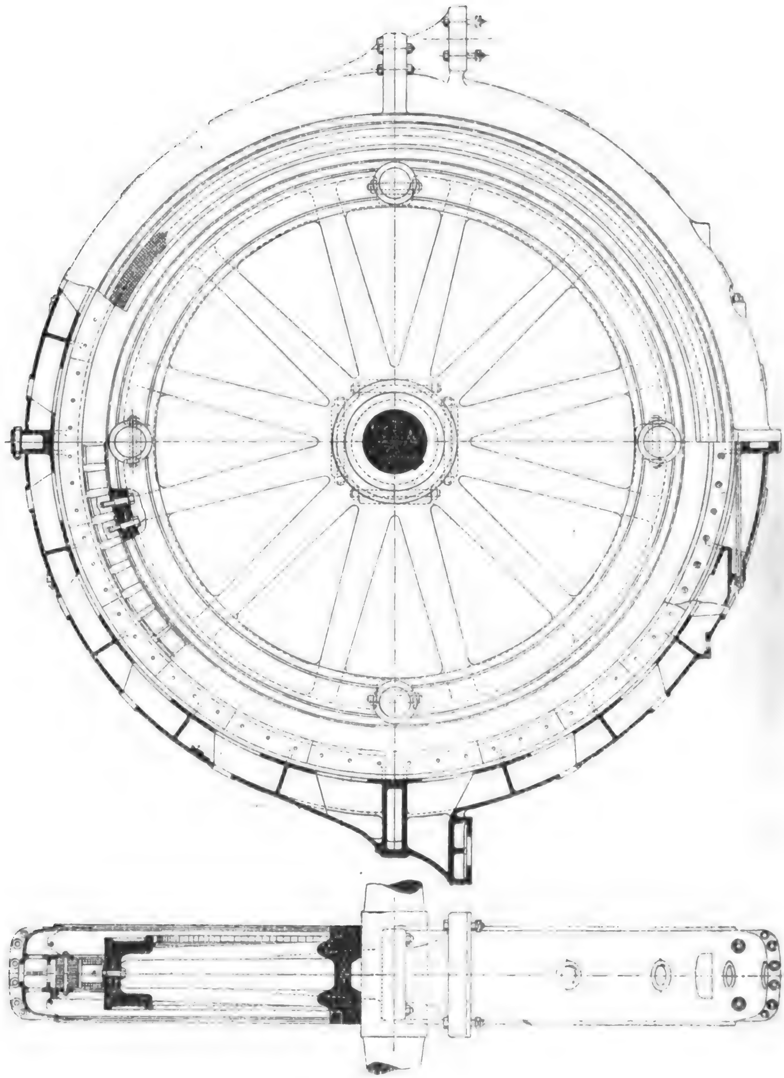


Fig. 9.—Lahmeyer's 1,600 k.w. Generator.

they are perhaps the largest machines in this country, and if the present fashion for turbo-generators proves to be justified they will probably remain the largest.

Table III. gives the leading particulars of the generators.

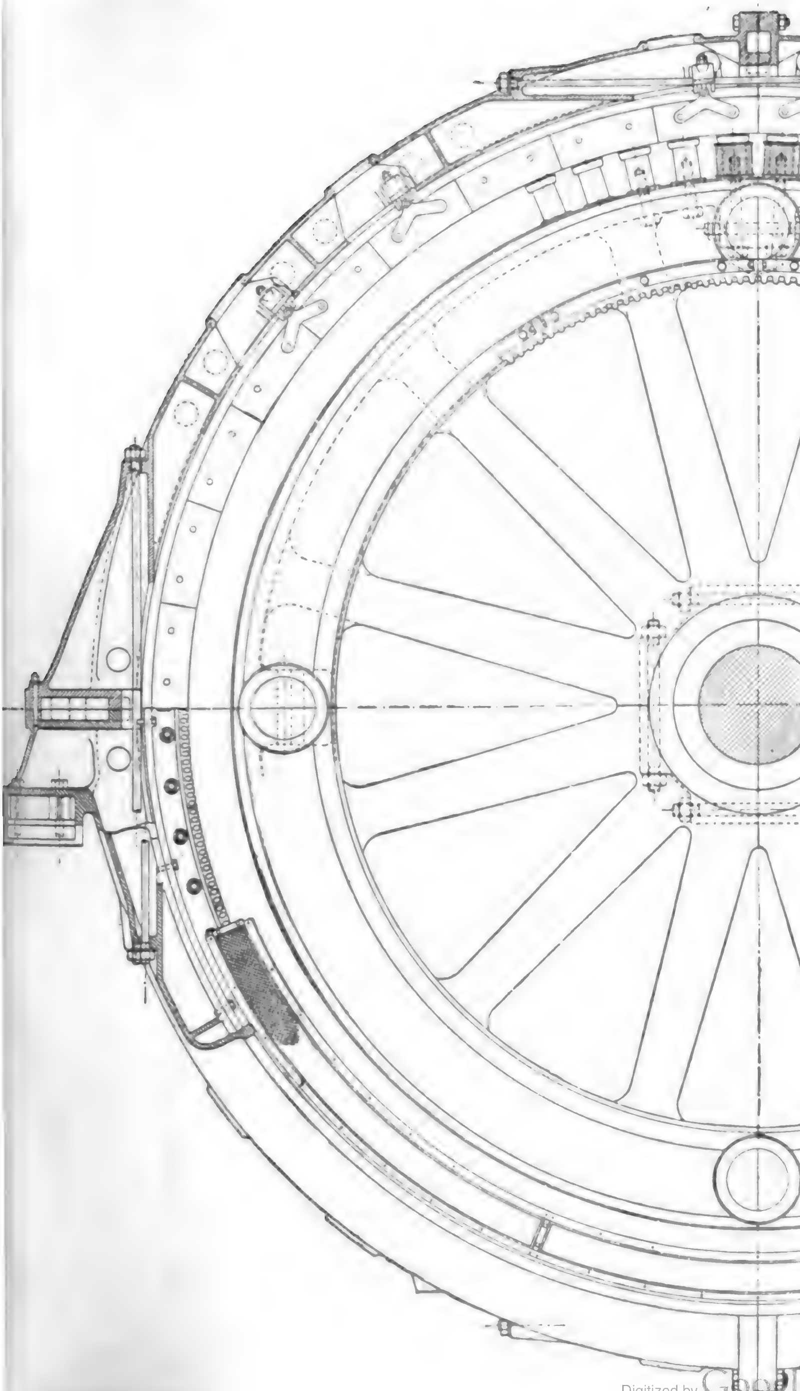


FIG. 10.—Lahmeyer's 4,000 k.w. Generator. Sectional Elevation.

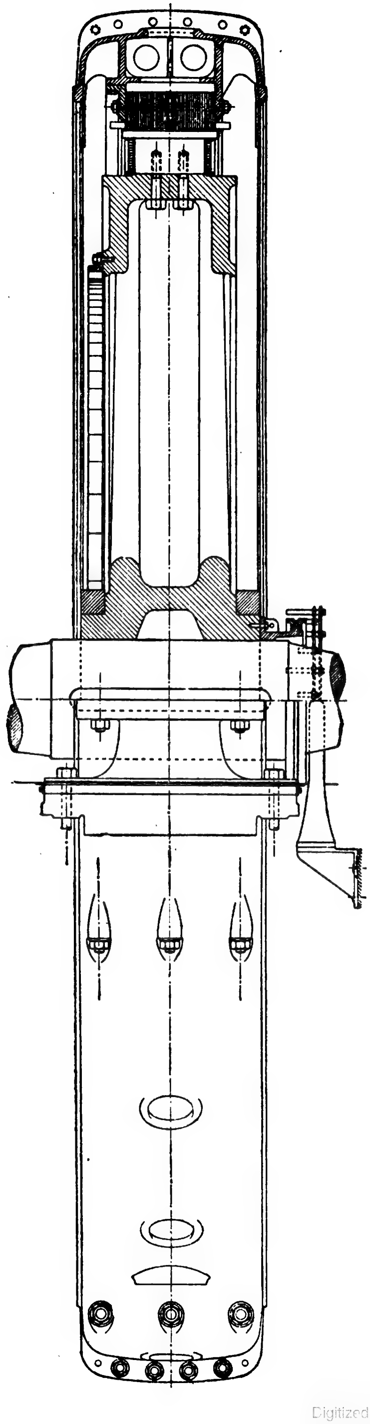


Fig. 11.—Lahmeyer's 4,000 k.w. Generator. Cross Sectional Elevation.

TABLE III.

Particulars of Lahmeyer Generators.

	800 K.W. Normal.	1,600 K.W. Normal.	4,000 K.W. Normal.
	ft. in.	ft. in.	ft. in.
1. Height above floor line ...	8 2½	17 1½	17 8
2. Centre of shaft above floor line	2 1	2 9½	2 7½
3. Extreme length in direction of shaft	7 5	21 0	19 0
4. Extreme width	15 1	33 0	39 4
Stator.			
5. Outside diameter of frame ...	12 1½	27 0	29 2
6. Outside diameter of iron core	10 2	24 7	26 7
7. Inside diameter of iron core	8 6½	23 0	25 1
8. Width of iron core	1 3	1 1	2 1¾
9. Number of slots per pole and phase	2	2	2
Rotor.			
10. Diameter of flywheel excluding poles	6 9¾	21 1½	23 0
11. Diameter of flywheel over poles	8 5⅝	22 11⅜	25 0
12. Number of poles	26	72	72
13. Type of poles	Solid wrough	t iron, bolted	to the wheel.
14. Pole winding	Wire.	Flat copper edgewound.	Flat copper edgewound
15. Flywheel effect, ft. tons ...	1,200	4,960	9,300
16. Total weight of machine, tons	30	131	197
17. Revolutions per minute ...	230	83·3	83·3

Main Switchboard.

Reference to the Figures 1 and 2 will show that the switchboard is at one side of the engine-room. It is arranged in two distinct halves, which, however, may be connected by an emergency switch. The generating plant is numbered consecutively, each of the odd numbers being connected to one half of the switchboard, and the even numbers to the other half.

The Figures 2 and 12 show that the switchboard is practically a three-decker. The resistances for the fields of the machines stand on the main engine-room floor underneath the principal switchboard gallery. The panels carrying the controlling gear are upon the principal gallery. The high-tension switches are placed on the upper gallery, and are worked positively from the principal gallery by levers.

At first, chimney-type switches with fuses in series were used, but a little experience with them showed that, although they were very satisfactory for small machines, they were not reliable in connection with large machines and long cables. They have, therefore, been replaced

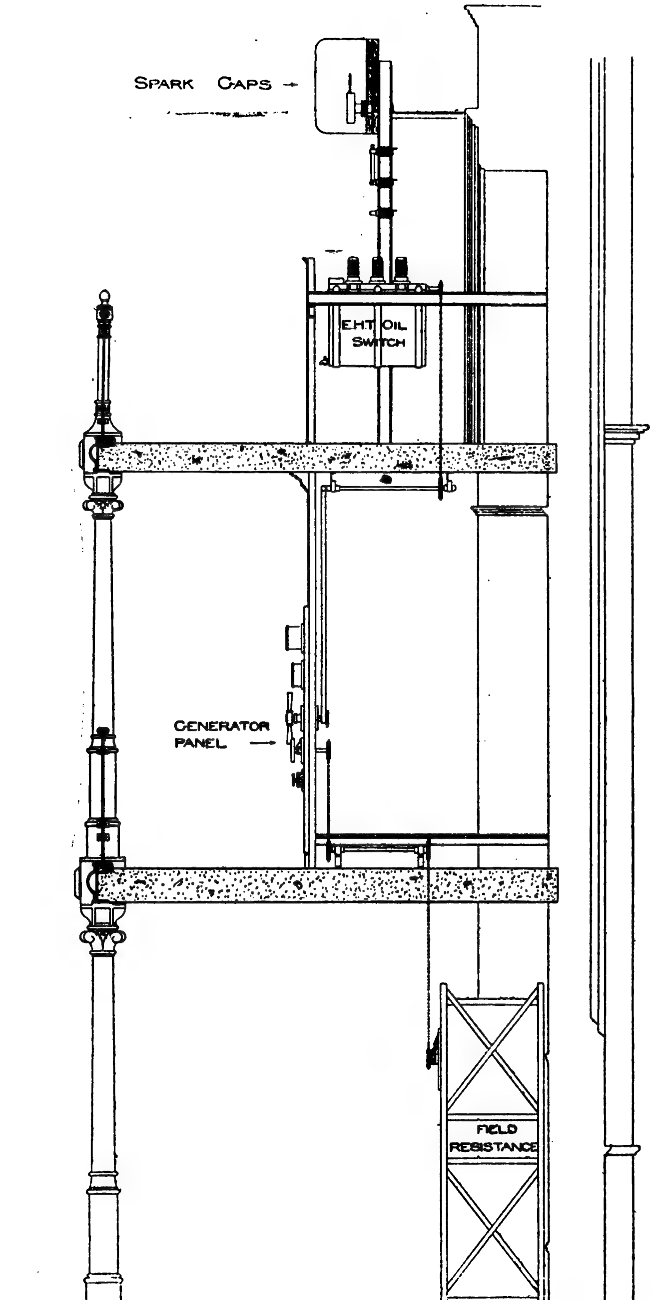


FIG. 12—Cross Section Main Switchboard.

by oil switches, which are also fitted with relays to act as automatic cutouts.

The measuring of the high-tension circuits is done under Messrs. Lahmeyer's Schuler patents, in which one coil of the generator is taken out to a one-to-one transformer, and from the secondary side of this transformer low-tension circuits are taken to the measuring instruments.

Each machine has its own panel complete, which carries its main switch lever, synchronising lamps, field ammeter, main voltmeter, wattmeter, and watthour-meter.

Each trunk main panel carries a watt-meter, ammeter, and watthour meter.

Each half of the switchboard has its own E.H.T. ring busbars, which can be divided into sections by suitable links.

Fig. 13 is a diagram of the main switchboard connections from the generators to the feeders, and shows the Schuler measuring transformer connections together with the two halves of the switchboard and the emergency switch by which they may be connected. It will be noted that the two sets of busbars are kept distinct with their own allotted machines and feeders, and that selector switches, by which the machines or feeders can be thrown on to either busbar, are not employed.

Cable Charging Gear.

Cable charging gear is provided in the shape of a small motor generator and two transformers with suitable connections, so that it may either be used to run up the cables to working pressure or to test them at 15,000 volts.

A three-phase generator is driven by a D.C. motor, and produces current at a normal 2,000 volts pressure. This current is then stepped up by a bank of two three-phase oil-transformers, and the pressure is varied by varying the field of the 2,000-volt generator. Special busbars and switches are provided in connection with the charging gear, so that a cable may be run up and then put in parallel with other working cables, or a working cable may be taken off the main bars and discharged for testing or other purposes.

Trunk Mains.

Ten trunk feeder mains at present leave the generating station; they are all three-core, lead-sheathed, paper cables. Six of them go to the City and four go to the West End; means of interconnecting the City cables and the West End cables are provided in the City. The cables are laid on the solid system in steel troughs, which are heavily bonded to comply with the Board of Trade requirements. The cables were ordered when it was believed that the Board of Trade regulations for H.T. applied to E.H.T., and under this rule half-inch insulation was provided between conductors and between conductors and earth, the latter so that the cables could be worked either with the middle point earthed or unearthed as might be found most

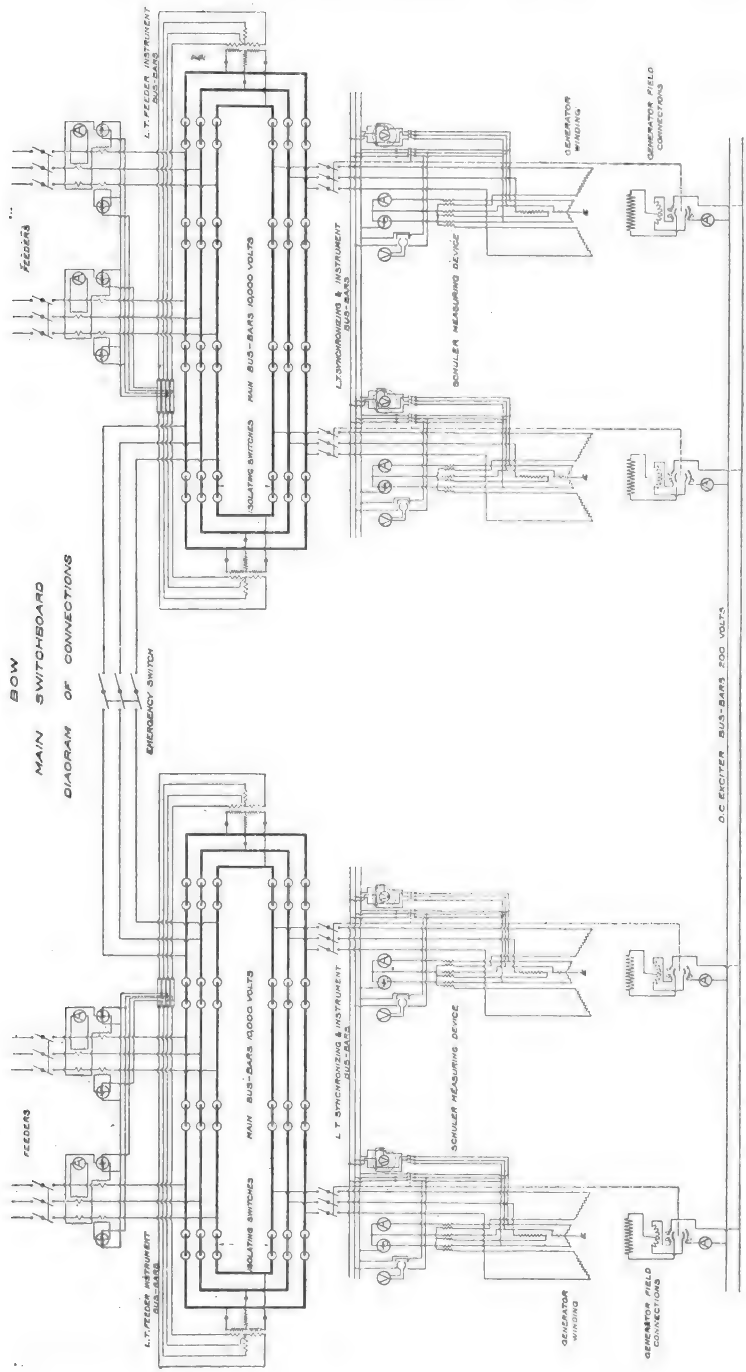

BOW
MAIN SWITCHBOARD
DIAGRAM OF CONNECTIONS
FEEDERS
L.T. FEEDER INSTRUMENT BUS-BARS
MAIN BUS-BARS 10,000 VOLTS
ISOLATING SWITCHES
L.T. SYNCHRONIZING & INSTRUMENT BUS-BARS
SCHULER MEASURING DEVICE
GENERATOR WINDING
GENERATOR FIELD CONNECTIONS
EMERGENCY SWITCH
D.C. EXCITER BUS-BARS 200 VOLTS
FEEDERS
L.T. FEEDER INSTRUMENT BUS-BARS
MAIN BUS-BARS 10,000 VOLTS
ISOLATING SWITCHES
L.T. SYNCHRONIZING & INSTRUMENT BUS-BARS
SCHULER MEASURING DEVICE
GENERATOR WINDING
GENERATOR FIELD CONNECTIONS

FIG. 13.

desirable. The author does not at all regret the extra paper, as, out of over seventy miles of cable, there has only been one cable fault.

There was an unfortunate circumstance attending the delivery of one lot of cables, due to the makers having over-dried them to get a high insulation resistance, but the author is pleased to put on record that they were promptly replaced by the makers, and since they have been replaced there has not been a single fault upon them.

Joints.—No boxes were allowed to be built on the route of the trunk mains; special joints, therefore, had to be designed which could be made in the steel trough without increasing the size of the trough or unduly diminishing the thickness of bitumen between the cable and the trough. Several types were tried; the original form selected is shown in Fig. 14.

It will be noted that it consists of two ebonite discs to keep the three cores in position; short copper sleeves were sweated over

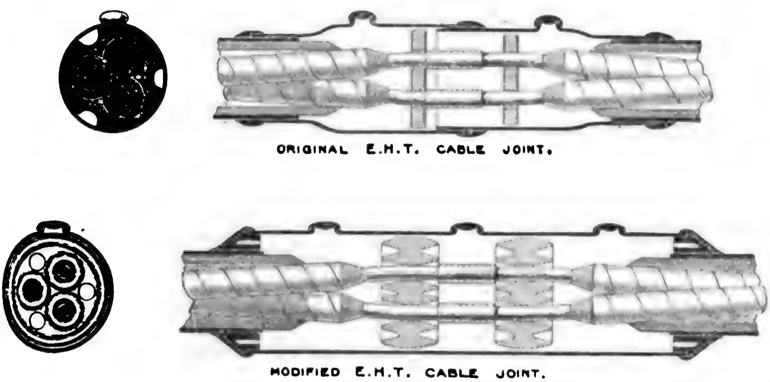


FIG. 14.—E.H.T. Cable Joints.

the three cores and a lead sleeve wiped on over all and filled up with cable compound. Further experience showed that the ebonite discs were better replaced by porcelain discs of the modified type shown, which give a longer path for creepage; the form of lead sleeve also was improved.

The heat due to filling the troughing on the solid system with hot bitumen causes expansion of the cable compound in the sleeve, and a void at the joint; this led to special precautions in the shape of short funnels, which were temporarily tacked on to the sleeve and projected above the top of the troughing. After the trough had been filled the insulating material in the sleeve was topped up, the funnel cut off, and the hole covered over.

SUBSTATIONS.

There are four substations in the City, each provided with a motor generator and battery plant. As the type of plant used in each is the same, a description of the Fenchurch Street substation will suffice.

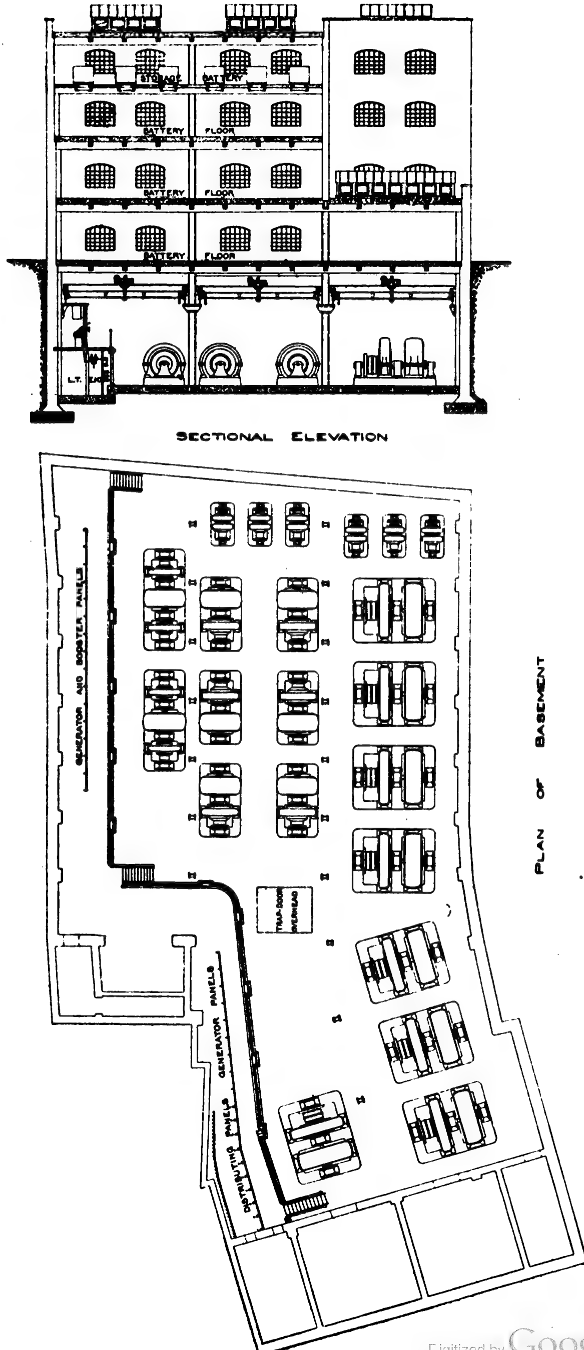


FIG. 15.—Fenchurch Street Substation.

Fig. 15 shows a plan of the basement and a sectional elevation of the building. It will be seen that it is arranged for machines and switchboards in the basement; the ground floor may subsequently be used as a battery-room, but it is very convenient for cable stores, trucks, and the other loose plant necessary for the street work of the mains department. The floors over are laid out for batteries.

This building will take motor generator plant of 8,400 k.w. capacity, and battery plant of 1,600 k.w. capacity on a four-hour rating.

Switchboards. — The E.H.T. mains are brought to the E.H.T. chamber underneath the switchboard platform, and are there connected through oil fuses to the ring busbars. Each motor is connected to the busbars through oil fuses and a Siemens & Halske chimney-type switch, which are also fixed in the E.H.T. chamber. The switches are controlled positively by levers from the machine operating panel on the switchboard platform above.

Each motor-generator has its own standard panel complete. Main switches, ammeters, voltmeters, also field switches and ammeters, are provided for both the motors and generators.

A synchronising gear of voltmeter and lamps combined is provided for the synchronous motors, and the motor field switches are omitted on the panels for induction machines.

The synchronous motors are all started up from the generator side, and the starting switch is used as the main switch for one pole of the generator, while the induction motors can be started alternatively from the generator side or from the motor side, and are fitted accordingly.

Motor-Generators.

Induction motors are preferred in some quarters because they can be started up more quickly, and it is believed that in the event of an accident they will maintain their load better than synchronous machines, which, however, are preferred by some engineers because of their better power factor. The regulation of the direct-current side can be managed equally well with either type of machine under normal conditions.

Rotary transformers have their strong advocates. For tram and railway work they are used largely of the fixed ratio type. Modifications of this type to give a variable pressure are more novel, but have been largely made by Messrs. the A.E.G. for the Berlin works. There are also other patents by Messrs. Lahmeyer and Mr. Lacour for variable ratio rotaries.

The small size of a rotary transformer as compared with a motor generator is very striking and seems much in favour; but it must be remembered that the necessary transformers are, like the condensers for turbo-generators, generally out of sight in a large basement, and the mind, if not the eye, must grasp them both together.

It is stated that rotaries will give a higher efficiency, but from any records that the author has been able to obtain of the practical working of the machines, the regulation, although good enough for a power load, is not usually sufficiently good for a high-class lighting load.

TABLE IV.

Particulars of Motor Generators.

Description.	Synchronous Type.	Induction Type.
Alternating Current Motor.		
1. *Overall Dimensions.*		
Height above floor line ...	7′ 11″	8′ 5½″
Centre of shaft above floor line	4′ 4″	4′ 3¼″
Extreme length in direction of shaft	14′ 9″	20′ 2″
Extreme width...	8′ 6″	8′ 6″
Revolutions per minute ...	300	365
2. *Stator.*		
Voltage, phase and cycles ...	10,000 v., 3 ph., 50 cycles	10,000 v., 3 ph., 50 cycles
Outside diameter of frame ...	8′ 4½″	8′ 4½″
„ „ iron core	6′ 10½″	6′ 8½″
Inside „ „	5′ 7½″	5′ 7″
Width „ „	1′ 3″	1′ 5″
No. of slots per pole and phase	2	3
3. *Rotor.*		
Diameter of flywheel over poles	5′ 6¼″	—
Outside diameter of iron core	—	5′ 6½″
Number of poles	20	16
Type „	Solid mild steel bolted to wheel	—
Winding	Wire	Bar winding in slots with slip rings
Continuous-Current Motor.		
4. *Field Magnets.*		
Material	Steel	Cast iron
Outside diameter of yoke ...	7′ 2″	5′ 10″
Inside „ „ ...	6′ 4″	5′ 0″
Width of yoke	1′ 4″	1′ 1½″
Number of poles	8	8
Type „	Solid, with mild steel laminated poleshoe	Solid, mild steel laminated pole-shoe
Radial depth of poles	10¼″	9¼″
Winding	Wire	Wire
5. *Armature.*		
Voltage and amperage ...	400–480 v., 875 a.	100–120 v., 1,500 a.
Outside diameter	4′ 3″	3′ 1½″
Air gap	0·275″	0·275″
Length of laminations ...	1′ 1¼″	10″
Number of slots	192	80
Winding	Series Parallel	Parallel
6. *Commutator.*		
Diameter	2′ 6¼″	2′ 1″
Length	9½″	1′ 3″
Number of segments	384	160
	Equalising connections	Equalising connections
Brushes	8 sets of 6 carbons	8 sets of 8 carbons

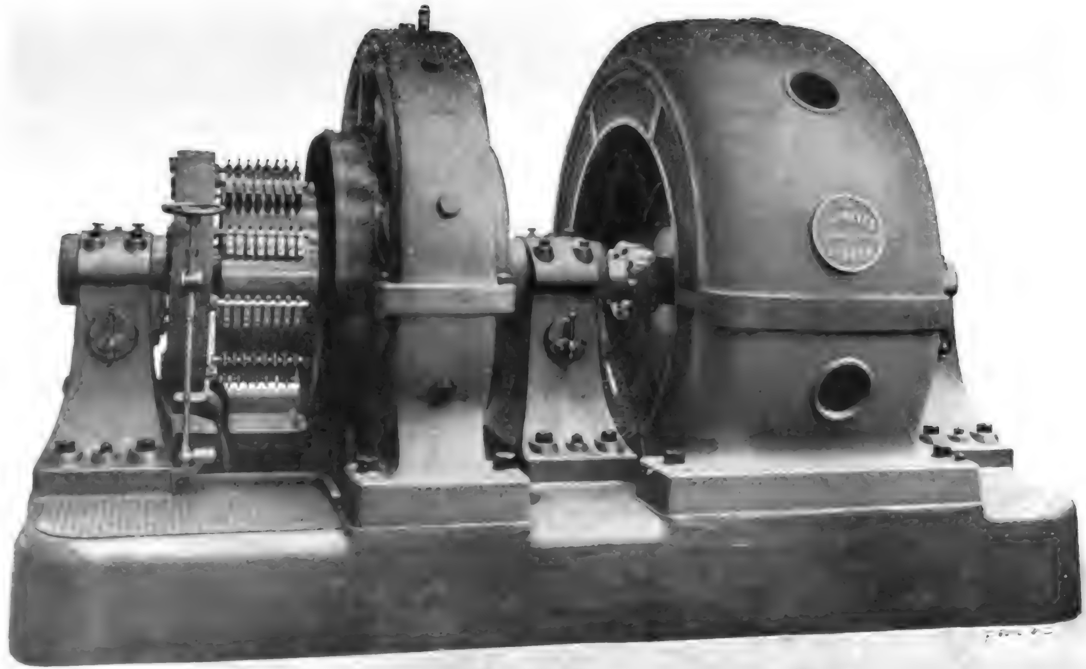


FIG. 16.—Lahmeyer's Synchronous Motor-Generator.

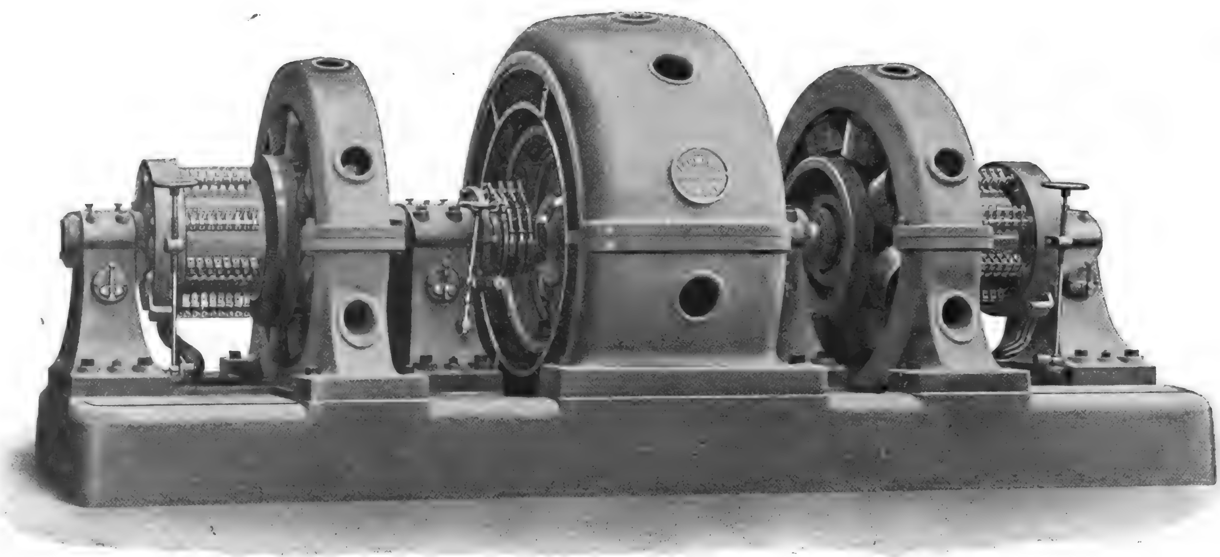


FIG. 17.—Lahmeyer's Induction Motor-Generator.

After investigating the types of rotaries then available, and carefully considering the respective merits of synchronous and induction motors for the particular case, it was finally decided to adopt synchronous motors for the majority of the machines with one or two induction motor sets in each substation. In all cases the motors are wound for the full pressure of 10,000 volts, with a uniform size of motor of 500 H.P.

Extreme solidity of construction was called for and heavy insulation to ensure freedom from interruptions, either mechanical or electrical. The results have so far quite realised the highest expectations. As so much, in fact everything, depended on the smooth running of these machines, the author did not feel justified in experimenting with light high-speed machines, and it will be very interesting to see whether the result of working some of the higher speed and lighter machines now being made is equally satisfactory.

The motors in some cases drive 350 k.w. generators wound for the full pressure, 400 to 440 volts, across the "outer" wires, and in some cases they drive two generators each of 175 k.w. capacity, which are wound for 200 to 220 volts, and are used as balancers on the three-wire system. Table IV. gives the leading particulars of each type of machine.

Fig. 16 is from a photograph of a synchronous machine, and Fig. 16*a* is from a working drawing and shows the same machine in sectional elevation. Figs. 17 and 17*a* are similar views of a balancer set driven by an induction motor.

Storage Batteries.

The batteries at Fenchurch Street at present comprise 204 cells, each of 4,000 ampere hours' capacity at a four-hour rate, made by Messrs. The Tudor Accumulator Co. The overall dimensions of each cell are 24 in. × 48 in. × 45 in. high, and its weight in the working order 3,000 lbs.

In accordance with the author's standard custom for several years past, end-cells are not used, their place being taken by reversible boosters. When he first used this system in the Short's Gardens sub-station the motors were wound for the Lambeth pressure 1,000 volts direct-current, to avoid double transformation losses. Had boosters with high voltage motors been used in the City, the size is so small that step-down transformers would have been necessary. It was therefore decided to use the ordinary pressure from the "outers" of the distributing network for running the motors. They are thus available at all times, no matter whether the E.H.T. plant is running or not.

As the author mentioned in the discussion on Mr. Highfield's paper on Reversible Boosters at this Institution in 1901, hand-regulation is used throughout. The conditions obtaining are better met by hand-regulating than by automatic regulation, which, although excellent for tramway work as used by Mr. Highfield, would not be so convenient for the work now under discussion. [A drawing of one of the machines is given in Dr. S. P. Thompson's "Dynamo Electric Machinery."]

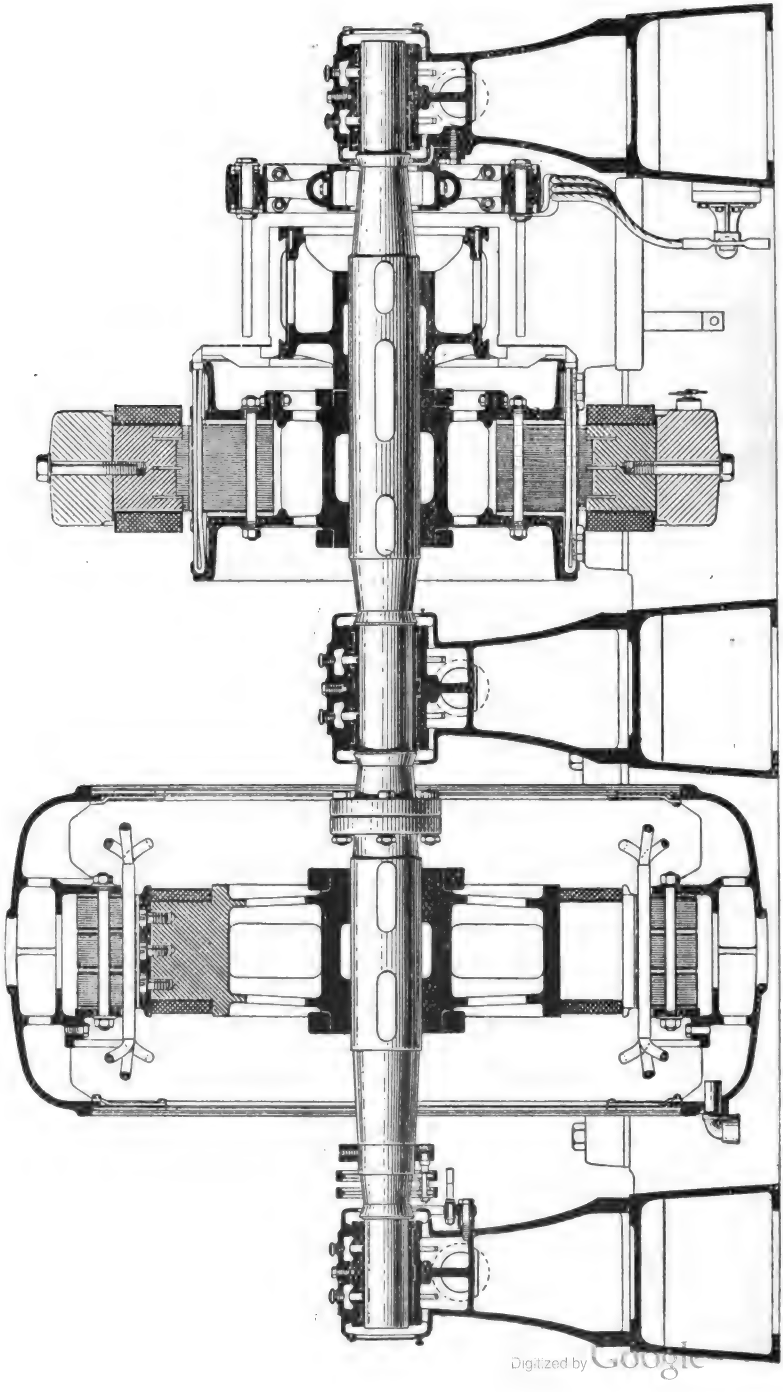


FIG. 16A.—Lahmeyer's Synchronous Motor-Generator.

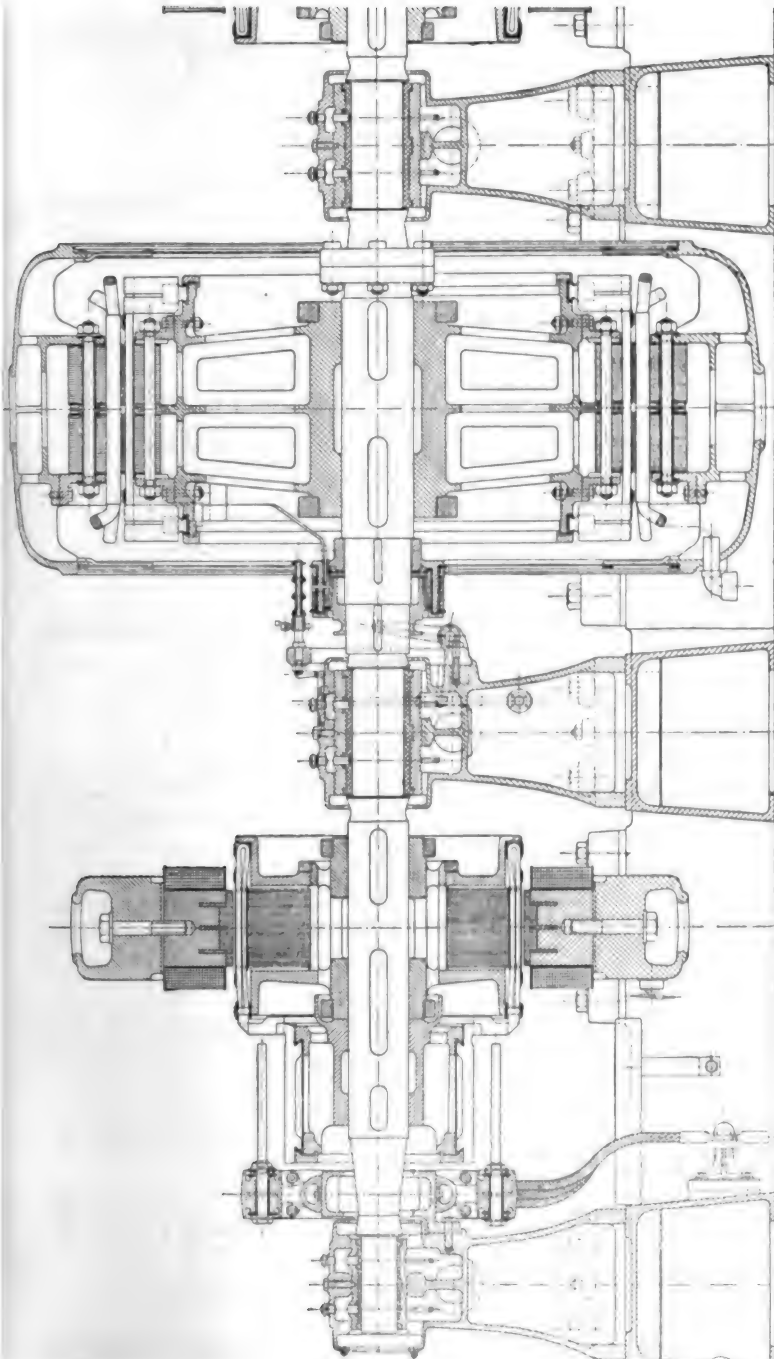


FIG. 17A.—Lahmeyer's Induction Motor-Generator.

Practically no movement of the brushes is required from no load to full load of 1,200 amperes. The latest construction is even better, as in it the generator machines are provided with compensation poles, and can be run from full load in one direction to no load, and up to full load in the other direction, without moving the brushes or showing any signs of sparking.

Battery-room floors have frequently caused some anxiety. In the author's experience, with small cells where there is apt to be a good deal of acid splashed and dropped, blue-brick laid on cement, but grouted up with pitch instead of cement, has proved thoroughly satisfactory. He has also used asphalte, but found that this was not sufficiently hard; the cell-bearers sink into it in course of time. In subsequent work where the cells do not stand on lead-covered steel joists they stand on concrete screeded over with a hard cement, smoothed off and tarred with two coats of Stockholm tar. This has been found to withstand any acid dropped on to it in the ordinary course of working, and has proved a cheap and efficient floor.

Supply.

The supply into the districts presents little novelty. The Ludgate area was first supplied from the Western districts of the Charing Cross Company at 2 × 100 volts on the three-wire system by simply extending the existing network, and supplementing the supply from the old substations with a temporary plant in Ludgate substation. Before Bow Generating Station was started there were more than 50,000 lamps supplied in this way: the pressure, therefore, was kept at 2 × 100 until this year, when a change to 2 × 200 volts began to be effected. The other three districts of the City, Fenchurch, Cannon Street, and Beech Street, are all supplied at 2 × 200 volts.

The feeders and distributors are paper insulated, lead-covered cables laid on the solid system, with spareways into which further feeders can be drawn as required. Each feeder is provided with an automatic cut-out in the substation, and the distributing networks supplied by separate feeders are interconnected through enclosed-type fuses.

General Working Results.

The Bow plant began to run in May, 1902. Fig. 18, showing weekly B.T.U. delivered into trunks and coal used, is interesting, as it indicates the value of the plant more truly than any other tests.

The units and coal are plotted on a 1 to 4 scale, and it will be noticed that almost throughout the coal used is less than 4 lbs. per unit.

The coal used at first was large Welsh, but in the second half of 1904 small Welsh began to be used in gradually increasing quantities, and through the winter not much more large coal was used than was necessary for lighting the fires, and a little on the peak. During the year 1905 the quantity of large coal used has been infinitesimal.

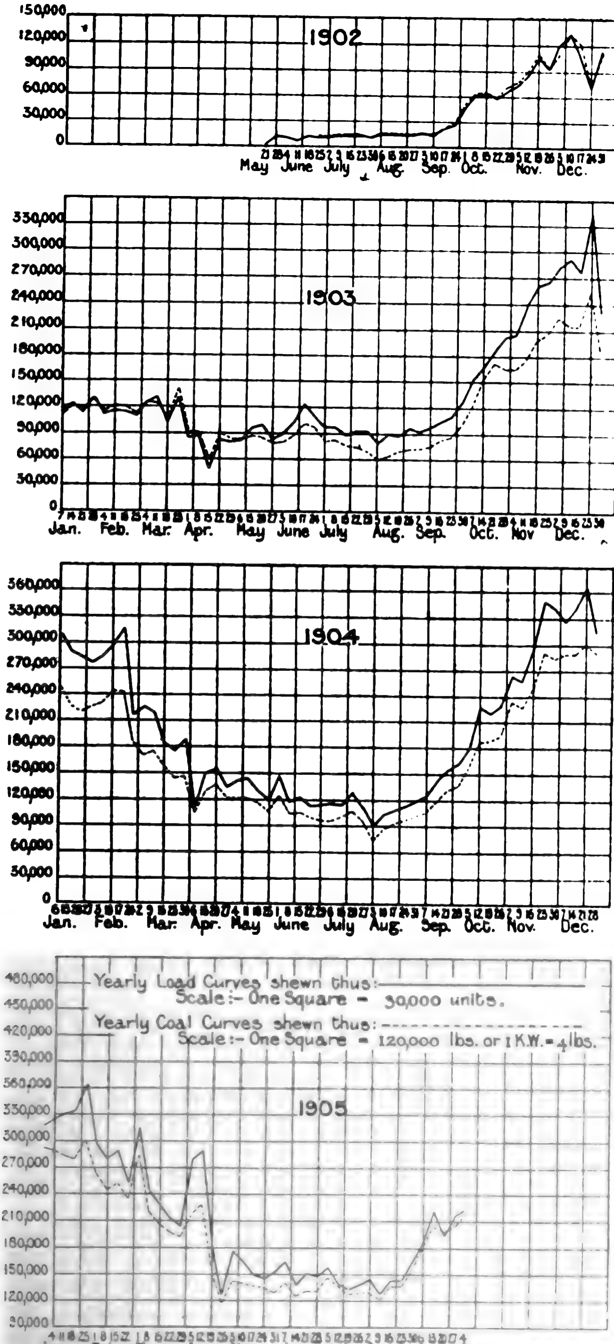


FIG. 18.—Output in k.w. and Coal Consumed.

As mentioned on page 83 the chimney-type switches first installed have been replaced by oil switches in the generating station.

Before the type of switch and fuse was decided upon in the year 1900 extensive test-room experiments were made, and under any conditions there obtainable the chimney-type switch and tubular fuses operated satisfactorily. Various fuses were experimented with. The type adopted consisted of two tubes in parallel. The main tube was of glass, about an inch and a half in diameter, and open at each end. It contained the main fuse wire. A second tube of ebonite, very small in diameter, containing a fine wire fuse, intended to break last and take the spark, was fitted in parallel with it. Experience, however, showed that laboratory tests are of little value as indicating the performance of switches and fuses which may have to open circuits under the working conditions which obtain in a large power plant. It was found that these fuses were apt to maintain the arc instead of breaking promptly when the 1,600 k.w. machines were working. A further set of experiments were then made, first in the direction of filling the glass tubes with cable compound and also with oil, neither of which were satisfactory, as the heat in the fuse wire was conducted away by the surrounding compound, and it was therefore impossible to correctly calibrate a fuse; and further, the small explosions made in the oil or cable compound due to the fuse acting, distributed the medium in the immediate vicinity and so rendered this type of fuse impossible for switchboard work. As the experiments were continued a type shown in Fig. 19 was developed, which has operated most satisfactorily. It will be noted that, while it is an oil fuse, the actual fuse wire is above the surface of the oil and covered by a little insulating chamber, which contains the metal vapour until it is blown under the surface of the oil as the bottom terminal of the fuse is dragged away by the action of the spiral spring.

The substitution of oil switches for the chimney-type switches in the generating station rendered the retention of fuses there unnecessary, but this type of oil fuse is now being used throughout the substations.

Previous inquiry as to the procedure with three-phase underground lines, none of which were working at more than 6,000 volts, and also with overhead lines at higher pressures, showed generally that no particular care was taken in switching the cables in or out; but the author was not satisfied that the plant herein described, comprising large machines and long underground cables, could be worked at 10,000 volts without special precautions; he therefore arranged for a complete oscillograph investigation to be made by Mr. W. Duddell.

In view of the great importance of the matter and the dearth of public information on the subject, the results of the investigation will be found in the Appendix. The investigation was undertaken jointly by the author's company and Messrs. Lahmeyer, and he is indebted to them for allowing the publication of the report, and also to Mr. Duddell for the thorough and painstaking way in which he

FIG. 19.—Oil Fuse.

carried out the tests. He also takes the opportunity to put on record his high appreciation of the debt that engineers owe to Mr. Duddell for the invention and perfection of the instrument which renders the carrying out of such tests possible.

The general scheme of the tests was first to take the pressure curves of the generators under steady running conditions with the station busbars only energised. Further curves were then taken of the machines running on one and more feeders, and also of the pressure between the cores of a cable when only some of the cores were connected to the busbars, the neutral point, as usual, being connected to earth. The curves taken under steady conditions were obtained on photographic plates.

The research was continued by investigation as to what occurred during switching when the records were taken on films. Preliminary switching tests were made at 5,000 volts, that is, half normal working pressure, when the maximum volts were found to be about twice the normal.

The result of the experiments was to show that resonance was more likely to occur if the periodicity was varied, and that, therefore, it was dangerous to switch a cable in at a low frequency and then run up to normal speed on the cable, and that the safer procedure was to switch in on the normal frequency with low volts and then raise the pressure.

It was then further shown that under working conditions, in the event of a circuit being opened through, for instance, the action of a fuse, a surge was likely to occur, and that it would be safer to provide spark-gaps. A spark-gap in itself, although a safety-valve for a surge, may start a rush of current which will cause further surges. The use of spark-gaps as a remedy may easily be worse than the disease; it is therefore very important to carefully consider the amount and form of resistance to be used in series with them. The common form of horn-type spark-gap was experimented with and abandoned in favour of a spark-gap of the type shown in Fig. 20, which has carbon on the one side and copper on the other. The travelling of the spark up the parallel portion of the horns is increased by the chimney action of the glass enclosure, and the result of many tests has been to show that they may be calibrated and set with much greater accuracy than the ordinary bent wire horn type.

As regards resistances, a non-inductive type must of course be used, and after many experiments an extended trial was made with the form of liquid resistance, also shown in Fig. 20, which consists of earthenware vessels filled with a solution of glycerine and water. What at first appeared to be unaccountable changes took place in some of the resistances; investigation showed that they were due to the action of sodium or other salt in the air. Alternative solutions have also been tried with sodium in them which were found to be more constant.

Further experiments have been made and are still being made in the direction of dry resistances, as, no matter how good it may

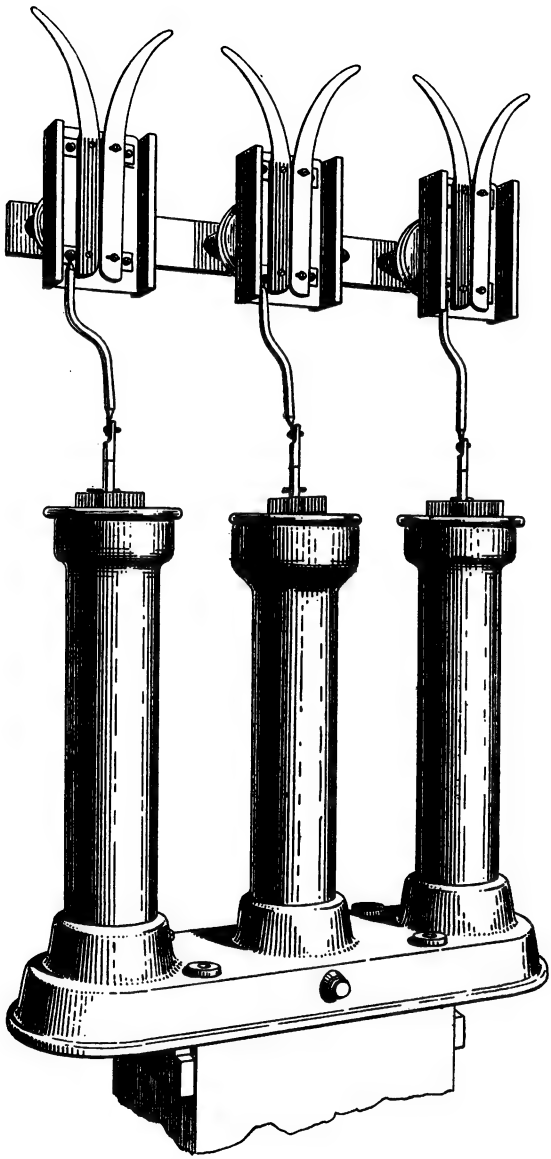


FIG. 20.—Spark Gap with Resistances.

be, a liquid resistance always has the disadvantage that it is liquid and may leak.

Attempts to obtain rods made of graphite mixture have not up to the present been successful, and forms of pressed graphite contained in cylinders, though satisfactory for low pressures, have not yet proved reliable for high pressures.

In view of the amount of high-pressure plant now being made, the author hopes that manufacturers will give attention to this detail, and produce a high resistance of small bulk which can be relied on under working conditions.

The width of spark-gap employed is 4·5 mm. for 10,000 volts working pressure, *i.e.*, 5,800 volts between each phase and earth with the centre of the star earthed. A spark will jump the gap at 12,000 volts when the horns are clean and the atmosphere normal.

Occasional and irregular working of the spark-gaps soon attracted attention, and the author determined to try and find out the causes which resulted in these surges. For this purpose a detector was extemporised for experimental use and subsequently adopted in a more permanent form.

Fig. 21 is a diagram of the connections. The apparatus consists of a small transformer with its primary inserted in the earth wire of the spark-gap resistance, without adding appreciable self-induction to the circuit, and a relay which is actuated by the secondary and rings a bell, or it could equally well mark a time recorder.

When a discharge occurs the relay shutter falls, causes the bell to ring, and so calls the attention of the switchboard attendant, who notes on a report form the exact time, and whether any change in switching or alteration in the conditions of running was made. These reports are then collected and examined with the running logs of the other stations, when frequently the effect in one place can be directly traced to the cause in the same or another place. But again there are many occasions when no cause can be assigned.

Irregularities when starting up machines, although not sufficient to affect easy synchronising or switching in, are prolific causes of spark discharges.

On two occasions small measuring transformers have gone to earth, and their failure not only immediately followed discharges, but was preceded by discharges during the previous day.

Faulty insulators have caused interruptions, and on nearly every occasion discharges have been reported, which emphasises the fact that sudden interruptions cause surges all over a system. Another curious fact is that after a failure the spark-gaps have acted for some time after all obvious indications of the trouble were over, from which it would appear that a system took some time to recover from a severe shock; in fact, it might almost be human in this respect.

The subject of surges is a very interesting one, and the author hopes it will be taken up in other quarters, and that such data may be forthcoming as will throw light on some of the unexpected incidents that happen in working E.H.T. plant.

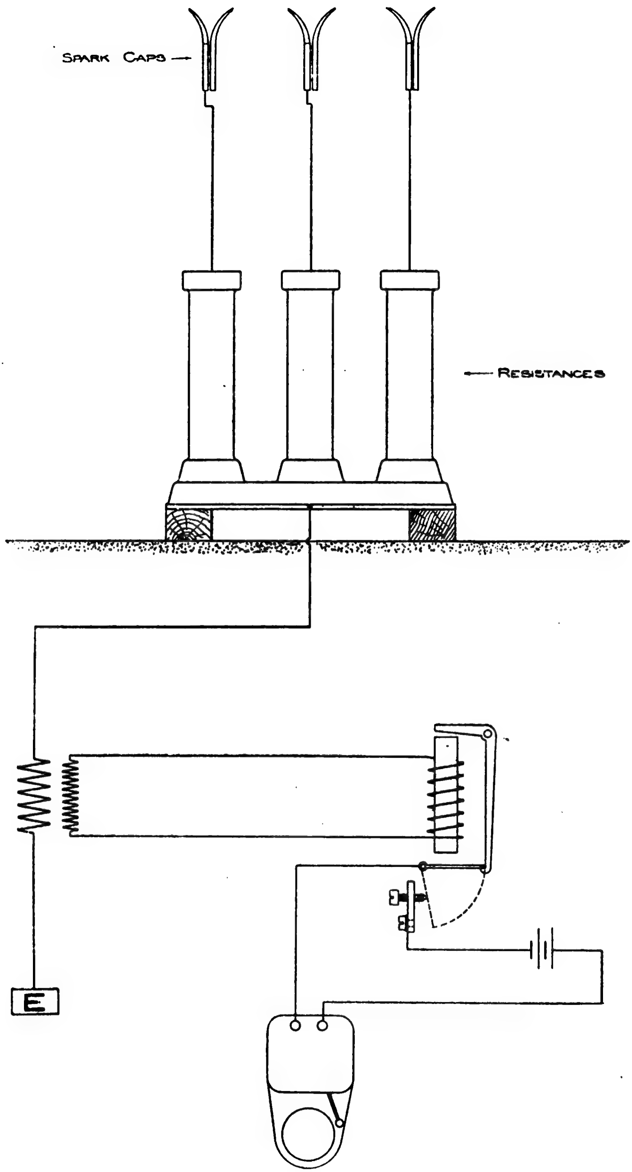


FIG. 21.—Diagram of Spark Gap Discharge Detector.

The author mentioned the effect of atmospheric changes to Professor Epstein, who subsequently found that he could so set a spark-gap that it would, when protected from dust, give very reliable indications of the humidity of the atmosphere.

In conclusion the author tenders his apologies to the members for the length of the paper, and for the omissions in it, many of which might be filled up by another paper if time permitted; and thanks to various manufacturers for the ready help they have given to him.

He also takes the opportunity of thanking his assistants for their help in carrying out the scheme and in the preparation of the paper; they are too numerous to name, but special thanks are due to Mr. H. W. Kingston, who took nearly the whole of the photographs shown.

APPENDIX.

Oscillograph Tests at Bow Generating Station.

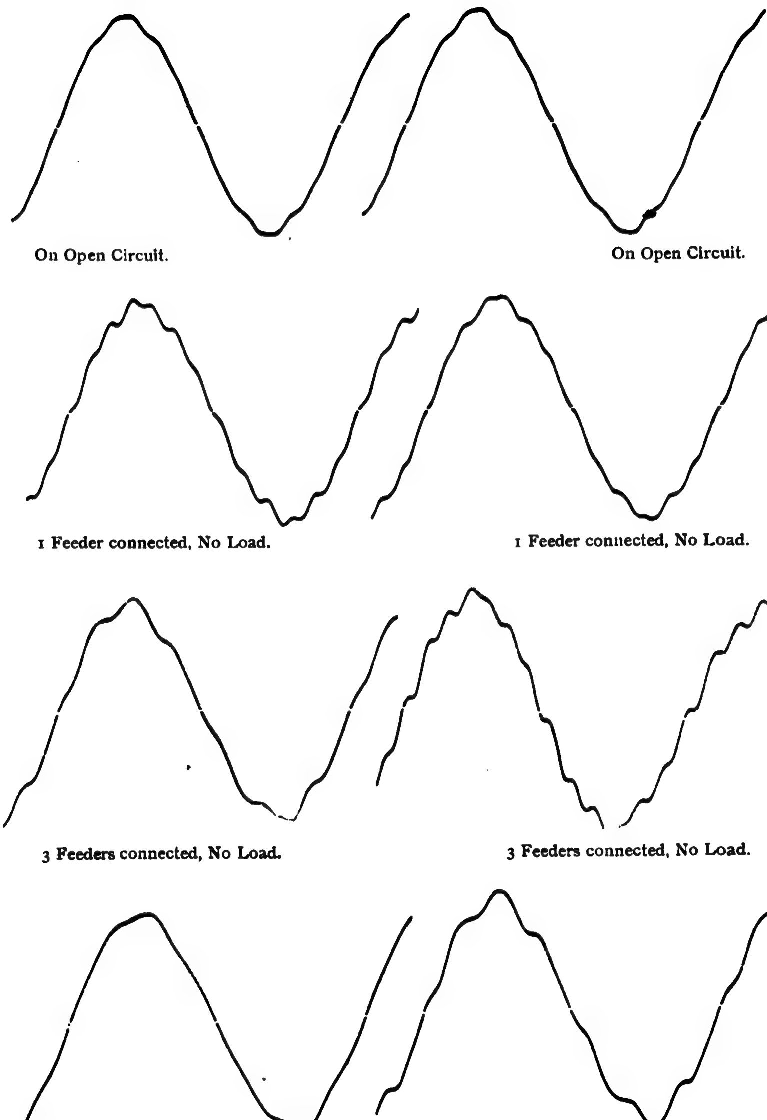
The accompanying wave-forms on Figs. 22, 23, and 24, show the effect of increasing the load from 0 to 500 k.w. on one of the small sets and the effect of the capacity of the cables on both machines. The wave-form with a load of 250 k.w. is very similar to that obtained when there was no load at the end of the feeders; the last curve with 500 k.w. is a little more irregular.

As the wave-forms are very satisfactory in shape under all the conditions examined, it remains to consider the possibility of dangerous conditions arising due to different arrangements or to future extensions. With the 1,600 k.w. machine there is a tendency to a resonance of the 13th harmonic with 3 City feeders, and to a resonance of the 11th harmonic with 4 City feeders; that is to say, with a capacity of 3 feeders the circuit formed by the generator and feeders has a free frequency of 650 ∿ per second, and for a capacity of 4 feeders 550 ∿ per second. Reducing this by Kelvin's law, the free frequency would be 1,100 ∿ per second for one feeder.

The resonances which may be dangerous are those of the fundamental, the 3rd (the 3rd harmonic exists between one terminal and the neutral point) and 5th harmonic. In order to obtain a resonance of the fundamental, which would be very troublesome and dangerous, the product of the self-induction into the capacity would have to be 484 times as large as with one feeder and one 1,600 k.w. machine. The self-induction of the 800 k.w. sets is probably double that of the 1,600, so that for a resonance of the fundamental with an 800 k.w. set about 240 times the capacity of a City feeder would be required; this is never likely to occur. The resonance of a 3rd harmonic is also for the same reason unlikely. A resonance of the 5th harmonic would require 19·4 times the capacity of a City feeder with a 1,600 k.w. set; and 9·7 times with an 800 k.w. set. This could therefore occur with the present plant, though it is not likely that nearly all the feeders will ever be connected to an 800 k.w. set at times of light load.

P.D. Wave-forms with neutral point of Generator earthed.

800 k.w. Alternator. 1,600 k.w. Alternator.



(Scale. 1 mm. = 1,000 volts.)

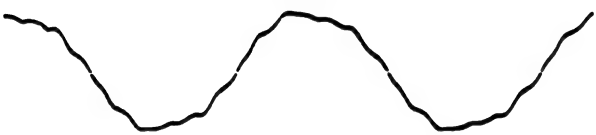
FIG. 22.

1,600 k.w. Generator energising 1 Feeder.
The Oscillograph was connected between Cores 2 and 3 of Feeder.
Neutral point earthed.

Only Core No. 1 connected to Generator.
No visible P.D. between Cores Nos. 2 and 3.

Only Core No. 2 connected to Generator.

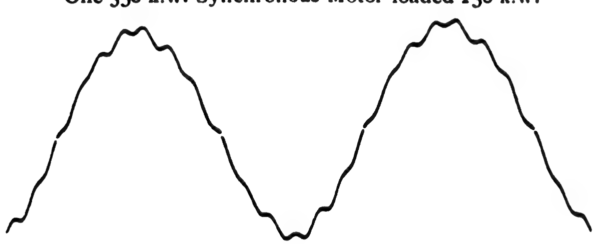
Cores Nos. 1 and 2 connected to Generator.



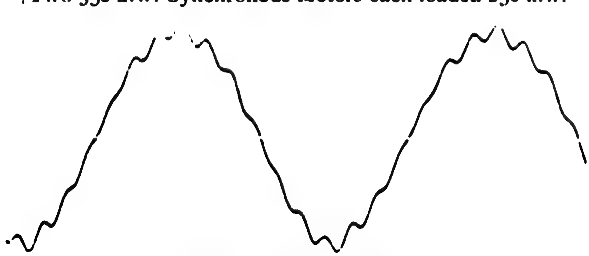
(Scale. 1 mm. = 1,000 volts.)

FIG. 23.

Station Busbar Wave-form at times of Light Load.
800 k.w. Machine. 2 Feeders connected.
Neutral point not earthed.
One 350 k.w. Synchronous Motor loaded 250 k.w.



Two 350 k.w. Synchronous Motors each loaded 250 k.w.



(Scale. 1 mm. = 1,000 volts.)

FIG. 24.

If at any time it is proposed to energise one or more of the feeders by means of any apparatus having a high self-induction, such as a very small alternator used with or without transformer, great care must be taken that the self-induction does not have such a value as to make it possible to have a dangerous resonance of the fundamental or one of the harmonics. It is to be noted that larger generators than at present installed will probably have *less* self-induction, and will therefore be, if anything, less liable to produce resonances; also several generators in parallel behave as if they had *less* self-induction than one machine. It appears, therefore, that as regards resonances the plant is very free from dangers.

Switching Tests at 5,000 R.M.S. Volts.

800 *k.w. generator switched on and off Cannon Street feeder on open circuit recording wave-form of P.D. between Cores Nos. 2 and 3.*

Frequency 50 ∿ per second.

The cores were switched on and off one at a time, the switching being made between brass contacts in air. There are many wave-forms omitted between one print and the next.

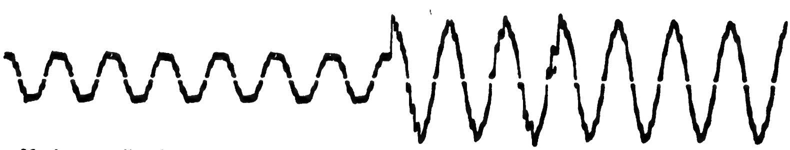
Neutral point earthed.

Switched on and off in the order 2, 3, 1.

Switched on Core 2.

Maximum volts 4,100.

Switched on Core 3.

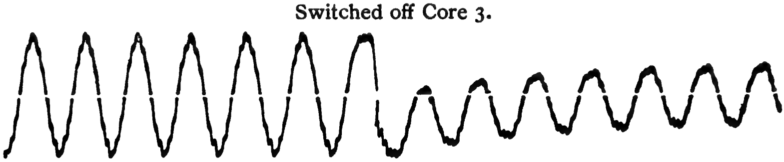


Maximum volts 9,800.

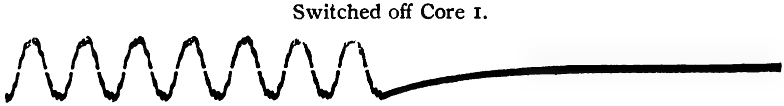
Switched on Core 1.
(No effect on wave.)

Switched off Core 2.
(No effect on wave.)

Switched off Core 3.



Switched off Core 1.



(Scale. 1 mm. = 1,000 volts.)

Fig. 25.

800 k.w. generator switched on and off Cannon Street feeder on open circuit recording wave-form of P.D. between Cores Nos. 2 and 3.

Switched on and off in the order 3, 1, 2.

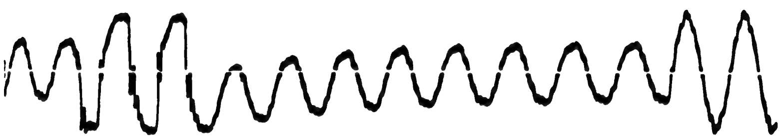
Switched on Core 3.

Maximum volts 4,000.

Switched on Core 1.

Maximum volts 5,000.

Switched on Core 2.



Maximum volts 8,000. Note : Sparked in making contact.

Switched off Core 3.

Switched off Core 1.

Switched off Core 2.

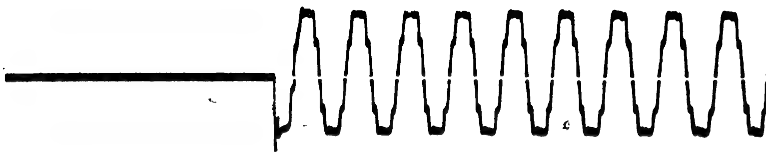
(Scale. 1 mm. = 1,000 volts.)

FIG. 26.

800 *k.w. generator switched on and off Cannon Street feeder on open circuit recording wave-form of P.D. between Core No. 2 and earth.* (*Lead.*)

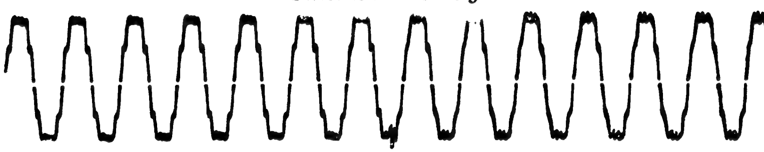
Switched on cores in the order 2, 3, 1. Switched off in the order 1, 3, 2.

Switched on Core 2.



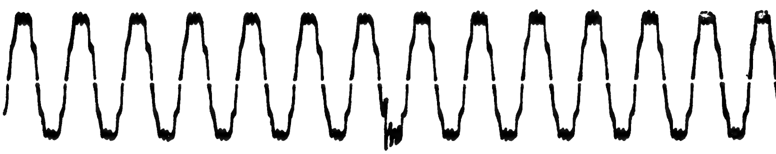
Maximum volts 4,900.

Switched on Core 3.

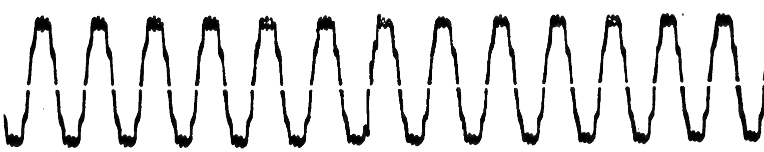


Maximum volts 4,400.

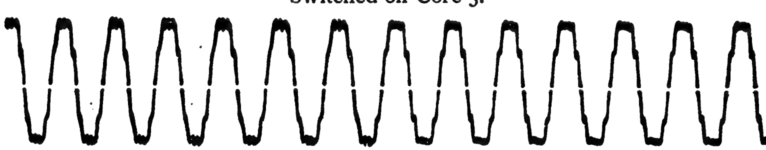
Switched on Core 1



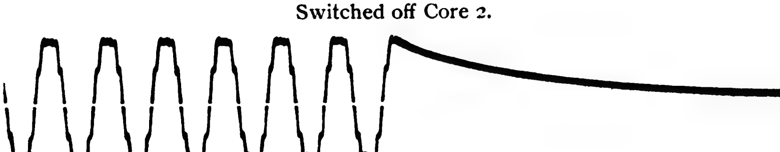
Switched off Core 1.



Switched off Core 3.



Switched off Core 2.



(Scale. 1 mm. = 500 volts.)

FIG. 27.

As might be expected, the highest P.D.'s are recorded when the oscillograph is connected between the first and second cores which are switched on. The highest instantaneous value of the P.D. recorded was 9,800 volts, or nearly twice the R.M.S. value (5,000), so that it should be just safe to switch on a feeder on open circuit at 10,000 R.M.S. volts: if the insulation will stand 20,000 R.M.S. volts, this would give a margin of safety of about 40 or 50 per cent.

The oscillations which occurred between the self-induction of the generator and the capacity of the feeder are very high frequency, and die down so quickly that it is difficult to estimate their frequency with any accuracy. Measurements on the films make the frequency about 750 ∿ per second, and this is in accordance with the value one would expect deduced from the tendency to give resonances under steady running conditions which have already been noted.

Any sudden change of voltage on the cable, or of current through the machine, will tend to set up oscillations whose amplitude will be the greater the less the losses in the system, so that any sudden changes in P.D. or current, especially when a cable is on open circuit, are dangerous. Thus it is dangerous to switch on an unloaded feeder or to switch off, or remove by a fuse, a very heavy load or short circuit, if by so doing any unloaded or lightly-loaded feeder is left connected to the generator. Added to the high P.D.'s produced by these oscillations, which do not seem to exceed three times the R.M.S. value, there are the much higher P.D.'s which can be set up when any unstable arcs or sparks occur in the circuit.

It is most important to avoid any arcs or sparks of any sort whatever occurring in the circuit, or they will probably produce sufficiently high voltages to break down the insulation. The breakdown of the insulation in a single place generally produces an arc or spark there, which in its turn aggravates the evil, producing still higher voltages and further damage. Thus a single tiny arc or spark may lead to the breakdown of a lot of valuable plant and cause an interruption of supply.

As it is necessary to be able to switch in and out feeders without shutting down the station, charging gear was provided for the purpose.

Discussion at Meeting of Dec. 7, 1905.

Mr. Carl Sulzer: I think Mr. Patchell has dealt with his task in such an able and masterly way that very little, if anything, remains to be added; but should any particular questions with regard to the engines be put, I shall be very glad to answer them. When Mr. Patchell entrusted to my firm the work of building the large engines, we quite realised the great responsibility and the confidence he placed in us. If I may mention a personal recollection, I would say that it has always been a great pleasure to me to discuss questions pertaining to engines with Mr. Patchell, who is such a very thorough engineer, not only in electrical matters, but in all matters relating to steam engineering. We have discussed the question of compounds against triples; we Mr. Sulzer.

Mr. Sulzer. have discussed superheat, jet condensers, direct-driven pumps, besides many other things, and Mr. Patchell's judgment has been responsible for the solution we have found to those questions. I think great credit is due for the able way in which Mr. Patchell has dealt with his task.

Mr. Sparks. Mr. C. P. SPARKS: I regret very much that the paper was not in our hands some little time before the meeting, as with a paper covering such a large ground as this it is almost impossible to speak without preparation. First, with regard to direct generation at high pressure, Mr. Patchell in the course of his remarks corrected the statement made on the second page of his paper with regard to the Deptford station, and I should like to add a word in addition to what he has said. The fact is that this generation of 10,000 volts direct by the alternator was not only the first in England, but I think we may claim credit for it being the first in the world, with underground cables, at such a pressure. I was connected with Mr. Ferranti at the time and worked out the design with him, and I know that these machines were projected in 1887 and worked on the supply of London in 1890. The next point as to extra high pressure machines is the interesting one which my friend Mr. Highfield drew our attention to last year in connection with the formation of nitric acid in alternator coils. I think Mr. Patchell's explanation on page 79 is the correct one, namely, "It appears to the author, therefore, that probably the acid is due to impurity of the insulating materials rather than to the destruction of pure material by ozone." My own view is that the proper way of building these coils is to impregnate the insulating material at a very early stage of the manufacture. The insulated wire should be treated by some vacuum process and impregnated with insulating material; or, better still, the whole coil when wound, if it is not a slot-wound machine, should be put into an impregnator, the moisture extracted, and the interstices filled with insulating material. When that is done, I think the difficulty which Mr. Highfield has drawn attention to is not likely to occur. The next note I have is with regard to cables on extra high pressure systems. I think the safety of these extra high pressure paper cables has been overlooked. It is the exception to get a fault on alternating-current cables. The difficulties of direct current due to electrolysis are very great, but when cables are carefully manufactured and carefully laid the deterioration on the alternating-current cable is very small. So long as the lead or sheathing is kept impervious to moisture, we may say there is no depreciation at all. I understand the cables in this case have been laid solid. That is, in my opinion, a mistake in such a city as London. Owing to the value of the road space and the expense of reinstatement I think a conduit system is the right system to adopt, so that repairs or additions can be carried out without inconvenience to the public. With regard to the site of the station, there are so few of us that have the opportunity of saying "This shall be the site of a great undertaking," that the choice of a site is of special interest. Without wishing to be critical, I should very much like to know why this site was chosen. If Mr. Patchell had to go several miles outside the area, why was not the site put even farther away, where he could

not only get the advantage of rail-borne coal but sea-borne coal direct in steamer, and water for condensing purposes in large quantities? With regard to the general lay-out of the station, there is one feature in the boiler-house, namely the chimney, which I have always envied Mr. Patchell every time I have seen the station. Owing to the regulations of the London County Council, we are not allowed to erect steel chimneys of the type used, inside London—it is thought to be a danger to the public; but by going outside the metropolis, away from the control of the County Council, Mr. Patchell has been able to avoid the London Building Acts and to put up steel chimneys, which, in my opinion, is the proper way to carry out work of this description. **Mr. Sparks.**

With regard to the boiler-house, I am not able from the figures I have seen to make any comment at the moment. The large boiler appears to me to be of very great interest to all of us, but without comparative figures before one as to what has been done elsewhere one is unable to appreciate how great the merits are, although I have no doubt that on investigation we shall find them to be of a very high order. With regard to the coal consumption of the station, here again I should like more information with regard to the load factor and the actual coal consumption. The coal consumption is shown on the diagrams to be below 4 lbs. per unit generated at the station, Welsh small coal being used. Under 4 lbs. may be a good figure, if it is 3·01; but, on the other hand, if it is 3·9 it is not, in my opinion, a good figure at all. As the station is equipped with the very highest class of steam reciprocating machinery, with the latest type of boiler, and with all modern improvements, I should have looked for a lower figure from this station, which has been running now for some two and a half years, than something under 4 lbs. of Welsh small coal. I hardly like to give any figures of the stations I am connected with, because they are old and the units are small; but, with North-country slack coal, we get a figure of 4¼ lbs. per unit generated, the cost of the North-country slack coal being less than the cost of the Welsh small coal delivered in London. But the date of these stations is hardly comparable with the Bow station, and the average size of the unit is about one-fifth. With reference to the concluding part of the paper, Mr. Duddell carried out some very valuable tests in 1902–3 for the County of London Electric Supply Co., about the same time that the tests were carried out for Mr. Patchell. We have derived very great benefit from Mr. Duddell's advice and from the experiments he made; and, as I have said before in this hall, I think all of us are very much indebted to him for his invention of the oscillograph, which helps us to investigate problems for which no other instrument was of any assistance. We had two types of switches then in use, one an air brake and the other an oil brake; but Mr. Duddell showed us that the oil-brake switch was the only reliable and safe form of switch to use; and I hope at the next meeting he will present some of the diagrams showing that this oil-brake switch does break at the neutral point. With regard to the fuses, the same thing applies—the oil fuse is the only safe form; and I entirely agree with Mr. Patchell that at the engine-house you should have oil-brake switches controlled by automatics in place of fuses.

DISCUSSION AT MEETING OF DEC. 14, 1905.

Mr. Sparks.

Mr. C. P. SPARKS: At the last meeting, when I commenced the discussion on Mr. Patchell's paper, owing to its reaching my hands at such a late date I was unable to refer to the paper in detail, and I suggested that the details of the boiler to which he has called our attention required time to investigate in order to compare it with other practice. With regard to this big boiler, I think the first point is to consider what is the limitation with regard to boiler practice. The limitation really is the size of the furnace. Assuming that you cover the whole of the available area of the stokehole with the furnace, then it becomes a question of building upwards to obtain the necessary heating surface. Mr. Patchell, by putting before us a boiler whose fire grate is the area on which the boiler stands, has reached the limit of boiler performance by covering the entire available area with fire space. With reference to the heating surface of this boiler, it is given —on p. 74—as 10,850 square feet. The biggest boiler I have used up to the present has a heating surface of 6,182 feet.

Mr. Patchell.

Mr. PATCHELL: That is only half the boiler. Two of these are set as one unit.

Mr. Sparks.

Mr. SPARKS: Two of mine are set as one unit; so that we will revise the figures to 21,700 square feet and 12,364 square feet. Mine are also set two boilers in one unit.

Mr. Patchell.

Mr. PATCHELL: Not in one block—one common furnace for two boilers; do not get wrong.

Mr. Sparks.

Mr. SPARKS: Referring to p. 74 of the paper, I see that the "upright boiler" is given as having a normal evaporation per hour of 33,000 lbs. and a heating surface of 10,850. That is the figure of 10,850 I am referring to. It may be a half unit or a whole unit. In the case I take the heating surface is 6,182 for one boiler which is half a unit, which would be therefore 12,364. If one compares the normal evaporation of these boilers, Mr. Patchell's gives a figure of 33,000 as against my figure of 20,000. The normal evaporation per square foot of heating surface in Mr. Patchell's case is given as 3·04; in the case of the boiler I quote it is 3¼. The ratio of the heating surfaces to the square feet of floor space occupied by the boiler in the case of Mr. Patchell's boiler works out at 21; in the case I refer to it is 18·4. The principal difference appears to be this very large over-load capacity which Mr. Patchell's boiler possesses, as he has run the double unit up to 100,000 lbs. evaporation, which is 50 per cent. over the normal. These boilers, I understand, are hand fired; in the case I quote they are stoked with mechanical stokers. With the mechanical stoker of the chain-grate type, which I use in this case, one is able to evaporate the full normal output of the boiler continuously; whereas with hand-fired boilers, although they possess great peak capacity if run at continuous load for ten or twelve hours, one is bound to deduct a very considerable portion of output for "fire-cleaning." In my opinion a boiler-house with hand-fired boilers requires to have 25 per cent. greater capacity than if it were fitted with

boilers with mechanical stokers. Then this boiler is referred to as dealing very well with the smoke question, using Welsh small coal. Well, we have other types of boilers, water-tube boilers, set with large combustion chambers, and when run with chain-grate stokers they also satisfactorily solve this smoke difficulty, and at the same time they enable you to use a lower priced fuel. With regard to the fog load, that is a common difficulty with us all in London, and from my experience I say it can be adequately dealt with by a mechanical stoker of the chain-grate type. There is one further point I should like to mention, and it is this. Mr. Patchell has given us figures relating to the Bow station. If he could in his reply give us figures showing the losses in the various parts of the system, so as to show us what is the coal cost of a unit delivered as direct current from the substations, I think it would be of much interest to the members here to-night. Mr. Sparks.

Mr. J. S. HIGHFIELD: I am glad to say that I have read Mr. Patchell's paper with great care. Mr. Sparks has dealt with the boiler question so completely, that all I can say is that I entirely agree with what he has said, especially with regard to the area of the furnaces and also the ability of mechanical stokers to deal with any fog load that one is likely to get. I should like, first of all, to deal with the question of pressure. Mr. Patchell says quite early in his paper that he decided, before putting up his station, to generate directly at 10,000 volts. In September, 1902, a 3,000-kilowatt generator was started at the Willesden station of the Metropolitan Company; the plant was put down under the advice of Mr. Todd, who was then engineer of the Company, and it generated directly also at 10,000—as a matter of fact 11,000—volts. In 1890, the Ferranti plant at Deptford also generated direct single-phase current at 10,000 volts. But what I want to point out is the great difference there is between the Metropolitan and Deptford plants and the Bow plant. The Metropolitan plant and the Deptford plant are working under far more difficult conditions than the Bow plant. At Deptford the current is 10,000 or 11,000 volts single-phase, and at the Metropolitan Company's works two-phase on a four-wire system, the latter plant supplying through two concentric cables with the outer conductor of the cables earthed at the station. At Bow the plant is three-phase; I believe the generators are star wound, and the centre point of the star is earthed, so that the pressure to earth at Bow on the 10,000-volt three-phase is only 6,400 volts, and the pressure between phases is 10,000. On the two-phase system the pressure to earth is a full 11,000, and the pressure between phases is 15,000 volts, so that the difficulties in handling two-phase current, four-wire, with one pole on each phase, are practically twice what they are in handling three-phase current. This example indirectly makes clear the great advantage of three-phase over two-phase or single-phase current for transmitting power over long distances. With the same pressure of transmission the insulation difficulties to earth—and those are the worst difficulties—are practically halved. I have a little more to say about the question of pressure later on. Mr. Highfield.

Mr. Highfield.

With regard to the switchboard and switch device I have very little to say, except with regard to cable charging. Cable-charging gear is used at some stations, but is not used at others. I am bound to say that two years ago I was convinced that some sort of cable-charging system was a necessity. It is particularly useful, as Mr. Patchell points out, to have a permanent gear by means of which the cables can be charged to a greater pressure than the ordinary working pressure. In the case of laying-in a new main, or a fault at the joint, it is very convenient to be able to charge up the 15,000 or 20,000 volts. Quite recently, within the last year, we have installed a new lot of switchgear with oil switches, and by accident, the first time we switched out seven miles of concentric main, 0·25 sq. inch copper section at the full working pressure, and switched it in again, and we do this habitually, just like you work the ordinary direct-current feeder. So that if you can make the whole of the insulation strong enough to stand the great strain which that operation involves, it seems to me it is a great advantage to do away with the whole of the cable-charging gear and simply switch the cable straight in. The only precaution we have taken is to keep some small transformers, working voltmeters and such like, connected at various points along the length of the cable.

Now I come to a point that I am rather interested in, and as it is a matter of some importance from the point of view of the makers of the generators with which we had trouble, if you will allow me, I should like to go a little fully into the question. I refer, of course, to the paragraph relating to some published matter of mine on the deterioration of alternator coils. Mr. Patchell says his idea is that the acid is probably present due to impurities in the insulating materials, rather than to the destruction of pure material by ozone. In my little article in *The Electrician* (vol. 54, p. 573), I particularly state that the insulating materials were of the best possible quality, and the workmanship, as far as one could see, was also of the best; so that all I can imagine is that he has not gone very fully into my argument. I would like, if you will allow me, just to explain the point about this nitric acid. We have two machines of 3,000 kilowatts capacity generating, as I explained, direct at 11,000 volts. One of these machines ran for something like a year without trouble. At the end of that time it broke down, so we took out the coils that had failed; in taking them to pieces we discovered that the whole of the cotton braiding on the copper had failed, and that its place was taken by a green material. I have here one of the actual tubes. It is simply a micanite tube through which the braided conductors are threaded, the copper being of rectangular section; and on running the hand down the copper we found little projections, a sort of roughness on the edge of the copper bar. The whole thing was analysed very carefully for the Metropolitan Company, and the presence of nitrate of copper and sulphate of copper was discovered. A number of independent analyses were made for us by Professor Wilson, of King's College; and, on behalf of the makers of the machines, Professor Gintl made

a similar set of analyses. The result of all these analyses was to show the presence of a large amount of sulphuric acid, a certain amount of nitric acid and nitrate of copper, and a lot of odds and ends which did not concern the question. In the pure insulation, in a coil that had not been used at all, we found no nitric acid and no nitrates of any sort, but we found gypsum, which is a very ordinary thing to find in insulating materials such as cotton. The smell of ozone when the machine was running and the roughness of the conductors showed that discharge had taken place, and it was at once surmised that the nitric acid was formed electrically in the way discovered by Cavendish some hundred years ago, by the ozonisation of air in the presence of slight moisture. The presence of the sulphuric acid was evidently due to the nitric acid combining with the gypsum and liberating sulphuric acid, and the explanation of the damage to the coils was at once clear. The rate of action is determined very much by the presence of moisture. If you have a perfectly dry coil you get very little damage. On the other hand, with a damp coil a great deal of damage happens; so that although a machine may be built to work perfectly well in a dry climate, these hand-wound coils in a tube will not work for any length of time in a damp climate. We stripped one winding entirely; we took the whole winding down and examined every coil, and it was exceedingly interesting to find that this action started to a very slight degree at the point of the winding that represented 2,000 volts. It increased very rapidly with the pressure, and above 8,000 volts the insulation of the coils was destroyed. But there was some variation. You could not say that they went gradually worse. Some coils were much worse than others, although run at lower voltage, and no doubt that is due to the presence of extra moisture. In order to reproduce the whole conditions I took these tubes, and put in the tubes this copper gauze. I used gauze because it offers a lot of sharp points, so that the action takes place much more quickly. I wrapped round the gauze some ordinary French filter paper, connected the gauze to the 10,000-volt transformers and earthed the tinfoil in the middle of the tube. In three days the action had advanced sufficiently to rot the paper, which was eaten away in places where the discharge had been greatest, and the copper gauze was green with nitrate of copper. It seems to me that this experiment, with the tests on the actual machines, proves to demonstration that the formation of nitric acid accounts for the whole of the trouble we have had. I do not see that there is any chance of absolutely preventing this formation by making the mica tubes of any workable thickness, and the only way appears to me to be to exclude the air entirely. If that is done I have no doubt that the machines can be made to run, but I must say that I consider 11,000 volts above earth, not three-phase working, or about 18,000 volts three-phase, is getting towards the maximum pressure at which you can generate directly in this climate. Mr. Highfield.

Mr. W. H. Booth: The interest of this paper, so far as the discussion is concerned, lies rather in what has been omitted than in what has been put in. There is very little information as regards output or Mr. Booth.

Mr. Booth. temperatures, so far as the steam end of the plant is concerned, and one can only take the general principles. In the first place, so far as one can judge from the drawings in the paper, the boiler furnaces are not particularly well designed for burning ordinary coal. Welsh coal is burnt, but it is not always possible to get Welsh coal. It seems to me that there would be a considerable amount of smoke made in all those furnaces, especially those under the horizontal boilers, if ordinary coal had at any time to be used. I should like to hear from Mr. Patchell what he has done with regard to making thoroughly airtight the doors of the secondary furnace. I think the secondary furnace is a very good idea so long as the ashpit doors and furnace doors can be made thoroughly tight—not merely planed and faced, because they would soon warp with heat. There ought to be a joint of an elastic nature, like a ring of asbestos, if the doors are to be made thoroughly tight. Then Mr. Patchell speaks of the back sections of the boilers acting as economisers. I can scarcely think that that can be the case, because, so far as can be made out from the limited details given, the back sections of these boilers will be as hot as the front sections, that is to say 370° F., so that the waste gases must pass away at a temperature of something like 600° F. Can Mr. Patchell give us any close idea of the temperature at which these waste gases go away, because if they go away at 600° F. the lack of economisers seems to be a very serious fault, and if the back sections are really so cool as we are asked to believe, then the boiler proper is being fed with water much below the temperature of evaporation. That leads one up to the consideration of the question of stage heating in the production of steam. The only feed heating appears to be by means of a coil or surface condenser placed in the path of the exhaust steam. If the vacuum is at all reasonably good the temperature of the condenser must be pretty low, and the exhaust steam from the cylinder must be very nearly as cold as the condenser temperature, so that, comparatively, a small amount of heat will be given to the water on its way to the boiler. Then with regard to the position of the steam dryer or superheater. I believe Mr. Patchell is no great believer in superheat, but he is a strong believer in dry steam. The position of the superheater should give him exceedingly good results so far as dry steam is concerned, but it is too far from the furnace to give superheat, and, if it were any nearer to the furnace, presumably such an uncontrolled apparatus would be exposed to the very serious risk of burning. If we look upon this station as a modern example, as one of the latest electric lighting stations for lighting a big city, it seems to me it is devoid of the modern principle of stage heating which should be obligatory in every modern station. Mr. Patchell gives us a list of the plant. He gives us no temperatures, and the only thing we can take hold of definitely is the amount of coal used per unit of output—about 4 lb. To give some idea of what can be done in the way of stage heating, I have had some figures prepared from a recently tested plant. The water is taken at the ordinary natural temperature, and is heated up by means of exhaust steam to 100° F., a suitable temperature for entry into the economiser.

It enters the economiser at that temperature and leaves at 230° F. It then enters the control pipes of the superheater at 225° F., having lost 5° F. in passing from the economiser to the superheater. It leaves the superheater for the boiler at 350° F.—that is to say, the boiler working at about 120 lbs. gauge pressure is at the same temperature as the feed water which enters it, and the boiler is made strictly to act as an evaporator and not as a feed heater in any sense. The temperature of the steam which enters the superheater is also 350° F., and the steam leaves the superheater at 495° F. It loses 30° F. in passing to the high-pressure cylinder of the engine. The engine is only a very ordinary sort of engine; it is nothing new; it is not a Sulzer engine, which we know will stand very high superheat; it is only an ordinary factory engine. The steam leaves the high-pressure cylinder at 258° F. Between the high-pressure cylinder and the low-pressure cylinder there is a re-heater, which is fed by means of superheated steam. The superheated steam passes through the re-heater, superheats the exhaust steam to 275° F., and the whole of the steam that passes through that re-heater goes into the boiler by way of the return water-control pipe of the superheater. Thus the only heat that the water loses, apart from radiation loss, is just the amount of heat it puts into the steam entering the low-pressure cylinder. As a result of that system we find that the I.H.P., which was formerly 367, has been reduced, doing the same duty and output, to 348—(I presume that is due to the decreased resistance within the cylinder of the engine)—and on the average of the same nine months of work in 1904 and 1905 there is a reduction in the coal of 200 tons on a total of 730. Originally, before the addition of the stage heating of the superheater, 1·82 lb. of coal per I.H.P. hour were used; after the addition, 1·40 lb. If these figures are worked out it will be found that this system of steam raising, though only connected with a very small factory plant, gives very much better results than are obtained by large plants with the ordinary system of steam raising, that is to say by jumps instead of a steady range of temperatures. Mr. Booth.

The following are the full particulars of the steam plant at Low Bridge Mills, Keighley, which is the one referred to above. They cover the nine months, February to October, inclusive, of 1904, *without superheater;* and the nine months, February to October, 1905, *with a Cruse controllable superheater* :—

Details of Plant.

1 Lancashire boiler, 28 ft. by 8 ft. by 150 lb. working pressure.
1 Cruse controllable superheater, 16 pipes, 200 sq. ft. steam heating surface; 80 sq. ft. water heating surface (copper control piping).

(Added in January, 1905.)

1 Green's economiser, 96 pipes.
1 inverted vertical compound condensing engine; Corliss gear to both cylinders; Horsfall compound regulator governor: H.P. cylinder, 13 in.; L.P. cylinder, 26 in.; stroke, 3 ft.; revolutions, 100.

Mr. Booth. Re-heater, between H.P. and L.P., heated with superheated steam taken by a branch from the main pipe. The steam is blown through, and the exhaust is returned through the return water collector of the superheater.

During 1904, with "wet" steam, it was necessary to maintain the working pressure at the boiler at 150 lb. During 1905, with superheated steam, the pressure was dropped to an average of 120 lb. During both years the coal used was Yorkshire small slack, identical in quality and origin, the calorific value being about 12,900 B.Th.U. per lb. weight. Name: Rothwell Haigh-Smudge. Price: 4s. 8d. per ton at the pit, and about 6s. 9d. per ton delivered in boiler-house.

The proprietor reports: "No additional cost in oil, having used the same quantity and quality during each of the two periods."

No cost of repairs to superheater, boiler, or engine.

Observations during 1905.

Average gauge pressure, 120 lb. (against 150 lb. in 1904).

Water: Average temperature feed entering economisers, 100° F.; average temperature feed leaving economisers, 230° F.; average temperature water entering controller pipes of superheater, 225° F.; average temperature feed leaving superheater for boiler, 350° F.

Steam: Average temperature steam entering superheater, 350° F.; average temperature steam leaving superheater, 495° F.; average temperature steam entering H.P. cylinder, 465° F.; average temperature steam leaving H.P. cylinder, 258° F.; average temperature steam entering L.P. cylinders, 275° F.

Average vacuum: 27 in.

Indicated Horse-Power.

Average for 1904, 367 I.H.P. (nine months); average for 1905, 348 I.H.P. (nine months).

Hours run: During nine months, 1904, 2,060 hours; during nine months, 1905, 1,900 hours.

Altogether the I.H.P. for 1905 shows a lower average than that for 1904; the loads and outputs during the hours run were practically the same.

Total coal used for all purposes for steaming and heating, for banking at nights and week ends and for power: During nine months 1904, 730½ tons; during nine months 1905, 532½ tons.

Coal used for steaming, heating, and banking: Average per week for both years, *3 tons.*

The steaming and heating are effected with "wet" steam through a separate pipe from the boiler, and not through the superheater.

Net coal used for power:

		Per hour.
1904 (nine months) ...	730½ − 117 = 613½ tons =	0·2978 ton.
1905 " " ...	532½ − 117 = 415½ tons =	0·2187 "

Saving per hour = 0·0791 ton = 26·55 per cent. on power account.

Mr. Booth.

Coal used per I.H.P. hour, for power only:

1904 ... 613¼ tons = 1,374,240 lb. ÷ (367 × 2,060) = 1·82 lb.
(756,020)

1905 ... 415½ „ = 930,720 „ ÷ (348 × 1,900) = 1·40 „
(661,200)

Coal cost per I.H.P. hour at 6s. 9d. per ton delivered in boiler-house: 1904, 0·065 penny per I.H.P. hour; 1905, 0·050 penny per I.H.P. hour.

Coal cost per I.H.P. hour (reckoned at pit mouth), 4s. 8d. per ton: 1904, 0·045 penny; 1905, 0·035 penny.

All through the nine months of 1905 the boiler has been fed from the engine pump, through the economiser, and through the controller pipes of the superheater into the boiler at back. In the collector of the controller system of the superheater the feed water from the economiser is amalgamated with circulating water from the boiler; the mixture passes into the boiler at the boiler temperature and partially already as steam.

During the year 1905 it has been found advisable to reduce the length of furnace grate from 5 ft. 6 in. to 4 ft. The boiler is hand-fired.

The weights of coal given cover all the coal delivered to the mill during the periods mentioned and used for all purposes—for power, for heating and steaming the mill, for banking up at nights and week ends.

Assuming that the engine was driving an electric generator with an overall efficiency as between I.H.P. and switchboard of 87 per cent., the coal consumption per k.w. would be 2·157 lb. per hour. This figure, of course, excludes the mill warming and banking. Before alteration the figure would be 2·804 lb.

If the figures be worked on the whole of the coal used, they become—

For 1904 = 3·338 lb. per unit equivalent.
„ 1905 = 2·764 „ „ „ „

Economy on total account 17·2 per cent., due to the adoption of stage heating, fully heated feed water and superheat.

In addition to the above economies there is the economy due to the reduction of I.H.P. per unit of factory output. Nothing is included for this, but it amounts to a further 6 per cent. on power account.

If such results can be obtained from a small station, what might one not be able to do with a large station, since better economy is usually possible with larger plants? It will be noted that my figures are for a nine months' test, not for a test of a few hours as supposed by Mr. Patchell.

Mr. Rider.

Mr. J. H. RIDER: I am inclined to agree with Mr. Booth that the information, valuable though it is, contained in the paper is nothing to what Mr. Patchell will give us in his reply, as there are a number of things which I would like him to tell me about. On the first page of the paper he tells us where and why he found the site for his power-house. I cannot understand why, having selected 10,000 volts as the

Mr. Rider. generating pressure, he should not take the full advantage of that high pressure, and go to a place where he could get condensing water without the use of cooling towers, and coal delivered by ocean steamers. He went outside the County boundary, and only as far outside it as he could go to get rid of the London Building Act, in which I sympathise entirely with him; but I think he might have gone still farther. Had he gone down to the neighbourhood of Beckton, or somewhere down there, he would have been within the economical limits of transmission at 10,000 volts, and have had a number of advantages which his present site does not give him. He would have been able to get his condensing water without the use of this peculiar construction which the plan shows, and to get his coal up without transhipping either into barges from a steamer or by rail. Having selected 10,000 volts and the site for the power-house, he goes on to tell us that all his distribution is done by direct current, which means that all his energy goes through rotary transformers of one kind or another. That being so, I cannot understand why he did not choose 25 cycles per second rather than 50. In my opinion 25 cycles, provided you have to do all your distribution through transformers of a rotary kind, is much preferable to 50. I may mention in passing that it would have given some of our bulk supply schemes later on the chance of delivering direct to Mr. Patchell without the use of any rotary transformers to change the frequency. On page 67 Mr. Patchell makes a remark which I think is not quite right. He says that he adopted 10,000 volts as the highest pressure which he could deliver directly to his motor generators, because he wished to do away with the use of static transformers between the supply and the motor generator, and the extra switch gear necessitated by them. I fail to see what extra switch gear he would have required had he adopted static transformers, because, so far as I know, it is not the custom to put switch gear between the static transformers and the motor generator. You merely have the high-tension switch gear on the primary side of the static transformer, and the low-tension switch gear on the direct current side of the motor-generator. I do not think it is a fact that any extra switch gear is required. When we come to Mr. Patchell's boiler-house, we come to what is perhaps the most interesting part of the paper. I would like him to tell us, if he will, why he has gone in for hand-firing, and why he has not adopted any form of mechanical stoking. So far as I can see, the arrangement of coaling which he has adopted means that the coal is deposited in heaps upon the boiler-house floor, which, although very convenient for the stoker to get at, does not, I think, conduce either to a clean boiler-house or a proper up-to-date plant. I think the system of double grates is a very good idea indeed, particularly for those boiler-houses which are liable to be called upon for sudden emergency loads. I am very glad it is his experience that the vertical-tube Hornsby boiler will work practically without smoke, which is a corroboration of what one has been led to believe from Mr. Booth's remarks on former occasions. I quite agree with him that a vertical water-tube boiler is, with its large combustion chamber, much more likely to give you a smokeless

combustion than any horizontal type, where you have your water tubes practically right on top of the fire. On page 73 Mr. Patchell tells us that the evaporative capacity of a pair of these large boilers has been taken as high as 100,000 lbs. per hour. I would like to ask him, with reference to that statement and the figures given in Table I., where he gives the normal evaporation per hour as 33,000 lbs. for the same boiler, whether he is referring in the Table to half of the pair (*i.e.*, one boiler), which would make 66,000 lbs. normal for the pair, or whether we are to understand that the boiler which normally evaporates 33,000 lbs. will, on emergency, go up as high as 100,000 lbs. I cannot quite see that a boiler with an economical evaporation of 33,000 lbs. can ever be taken up to 100,000 lbs. On page 75 Mr. Patchell tells us how he gets his feed-water supply, and it seems to me he has gone in for a good deal of extra complication which is not required. Apparently he gets his water from two artesian wells, and he has to use pumps for getting the air pressure for lifting that water up to a tank in the basement below the pump-room. Then he has to use additional pumps to pump from that tank up into some large tanks in the roof. The water then comes down by gravity through what is practically a surface condenser in series with his jet condenser into hot well tanks in the basement, and then it is pumped into the boilers. I do not know why —perhaps Mr. Patchell will tell us in his reply—he did not pump directly by his boiler feed pumps from the tank in the basement through his water heater into his boilers. It seems to me he is losing a good deal both in pumping the water to the roof and then down again, and also in letting the water stand in his hot well tanks rather than pump it directly into the boilers. Apparently he is depending entirely upon these two 13-in. artesian wells for the boiler supply, and he tells us that these will give him up to 20,000 gallons each per hour. If you work out the amount of water which he requires for the plant now in the station, you will see that he will need about 40,000 gallons per hour for a 20,000-kilowatt station, and he already has in about 18,000 kilowatts. I would like to ask Mr. Patchell if he has any standby for his water supply, or whether he is dependent entirely upon his two wells, because if so he is apparently getting nearly to the limit of the output of those wells. It is very interesting to know that he is dependent entirely for his water supply upon these two wells. I have had to sink a well at our Greenwich power-house, and I find the water exceedingly hard; in fact, I have had to put in water-softening apparatus to deal with the water as make-up water. I would like to ask Mr. Patchell, as he is dependent entirely upon these wells for his whole water feed, if he has to use softening plant for the whole of the supply. When we come to the generating plant—and in that I wish to include the engines, the generators, and the switch gear—I am very sorry that we have to talk about plant made on the Continent. I think it would be interesting if Mr. Patchell will tell us whether he went abroad for his plant entirely on the question of cost, or whether it was on the question of efficiency, or both. Although I am not a believer in putting a ring-fence round one's town or country, I think if you can Mr. Rider.

Mr. Rider. get within your own boundaries plant of a suitable kind—which I happen to know you can—it is a pity to go abroad for it. Mr. Highfield mentioned the cable charging gear, and I rather gathered from his remarks that he was inclined to say it could be done away with. I am entirely of that opinion. We had a charging device put in for our high-tension feeders, but for the last twelve months we have not used it. If you only get in the right kind of cables you do not require any charging device at all, and in view of simplicity and getting rid of all complications you are better without it. I do not at all agree with the kind of charging device Mr. Patchell has decided upon, namely, a motor generator, because if you have to charge your cable by a motor generator it means that you are practically running up the cable through all the periodicities from 0 to 50, and you are very liable to get high pressures at certain low periodicities while running up, which you would not get if you switched the cable on directly. Not only so, but if you charge the cable from the motor-generator you have all the trouble of synchronising the cable before you put it on the busbars, just as if it were a generator. That takes a great deal of time, and is an unnecessary thing. Then we come to Mr. Patchell's trunk mains from Bow into the City. I gather from the paper that these are mostly laid upon the solid system. Having in view the great cost of laying mains in London—a cost which, by the way, some people have failed entirely to realise—I think Mr. Patchell would have been wiser had he adopted the draw-in system. At any rate I do not gather from the paper that, although he put in his mains on the solid system, he put in anything like the number of spare ducts which his large station would ultimately demand in order that he might pull in cables without again opening up the streets. The putting in of a number of extra ducts, once the road is open, is a very simple matter: it is the opening and the closing of the road which costs the money. In Fig. 14 Mr. Patchell gives us two very interesting illustrations of the way in which he makes his high-tension cable joints. On our high-tension mains we originally adopted a method somewhat similar to his, with separators; but after some experience we have given them up entirely, and we are now making our cable joints by means of linen tape which has been well boiled in resin oil, wrapped upon the joint, with mica between the layers, and have given up entirely any mechanical separation such as he shows here. I would like to hear from Mr. Patchell whether he has had any trouble on account of the porcelain insulator which he uses. When we come to Mr. Patchell's distribution system and have to consider his motor generators, we again are confronted with the fact that they are foreign made; but I think they are exceedingly good machines. I am very much pleased to find that Mr. Patchell has gone in for motor generators which will take the high-tension supply directly on the stator, rather than going in for rotaries, which means the use of static transformers. I quite agree with him on that point, but I do not agree with him in his adoption of synchronous machines. Apparently Mr. Patchell has deliberately gone to synchronous machines after experience with induction machines. I

have gone the other way. I have had a good deal of experience with synchronous machines, and I have gone altogether round to induction machines. I think induction machines, although undoubtedly they have their faults, are simpler; they will not fall out of step with any fluctuation or short-circuiting—which Mr. Patchell probably has not got, but which tramways have—and they simplify the switch gear to an enormous extent. You have no direct-current field to bother with, you can switch the high-tension current directly on to the stator without paralleling, and your rotor can be a short-circuited mass of metal. My opinion is that in the power-house as well as in the distribution system you should go in for the simplest plant you can get, cut the complications entirely out, and make the switch gear of the simplest possible kind. Although on a 6- or 12-hour test the efficiency, as measured to-day, may be low compared to another plant, the commercial efficiency at the end of the year, from the fact that you have no stoppages or breakdowns, will be on the right side. Throughout the paper, although we have had a number of interesting descriptions of machinery and apparatus, there is not a single figure about cost. I do ask Mr. Patchell to give us what we are all longing for, and that is, some figures as to the cost of his power-house and the cost of operation. He told us that it only takes about 4 lbs. of coal per unit, but he does not tell us what his coal costs per ton, so that we are not very much farther on. Will Mr. Patchell tell us what the capital cost per kilowatt of the whole power-house is? what his coal costs per ton delivered in the bunkers; whether he brings it by rail or whether he brings it by steamer; if he brings it by steamer, what it costs him to barge (that will be rather awkward, because it will show the power-house ought to have been on the Thames); what his load-factor is at the power-house, and what his working costs are? If he tells us that, he will have given us an addendum to the paper which will be more valuable than the paper itself. Mr. Rider.

Mr. A. VENNING: This paper naturally attracts the attention of all engineers engaged in the design of central stations. On analysing the component parts of the plant, I can hardly balance up the two sides. I find, for instance, on comparing the engine capacity with that of the boilers that the plant is either over-boilered, or, on the other hand, the engines are not very economical as regards steam consumption. Excluding the two 300-kilowatt auxiliary sets, 16,000 kilowatts of main engine capacity remain, for which boilers equivalent to 528,000 lbs. of steam per hour have been installed, both being reckoned on a normal basis. This gives 33 lbs. of steam per kilowatt, or, including the auxiliaries, 31·8 lbs. per kilowatt. Considering it on a basis of heating surface per kilowatt, I find it runs out at about 11 sq. ft. of surface per kilowatt. This is excessive, as I have found when using ordinary Corliss engines, in conjunction with water-tube boilers and burning a cheap grade of coal, that 10 sq. ft. of heating surface has been sufficient to deal with all loads; and in designing large plants I have gone as low as 8 sq. ft. per kilowatt and found this has been ample, even when working with saturated steam. If these engines with double-beat Mr. Venning.

Mr. Venning. valves are as economical as represented, then the boiler capacity is certainly too great. Coming to the cross-section of the engine-room, I find that the height of travelling crane above the floor is 36 ft. 6 in. clear to the underside of the travelling hook. It strikes me that the traveller might advantageously have been put up another 8 ft. at least, which would have allowed 10 ft. from the top of the runway girders to the underside of the roof truss. This would have given more clearance between the top of the engine and the bridge girders of the crane, so that in taking out the piston and piston-rod the danger of a swinging piston coming in contact with the top part of the valve gear and possibly damaging it would be eliminated. That is a point which is often overlooked, and, I think, should receive careful attention in station design. The Hornsby horizontal boiler is what may be termed in boiler phraseology a "three-decker," but I think it would have been more efficient and more economical if arranged in two decks with the same aggregate number of tubes. If the baffles had been placed in a different manner from that shown on the section, the evaporative capacity would have been increased and a better degree of superheat obtained, for as now arranged I think only 40° or 50° F. of superheat is possible. I should like to ask what degree of superheat Mr. Patchell gets with that arrangement. Coming to the vertical type of Hornsby boiler this seems to be a combination of the Stirling, Cahall, and another type, each having upright tubes. One point which does not commend itself to me is the number of tubes of varying lengths, thereby necessitating a larger number of spares than is usual with other boilers, and the arrangement of these tubes entails the provision of considerable height in the boiler-room to facilitate the removal and renewal of the same without interfering with the coal bunkers, tanks, etc., that may be placed overhead. Reference has been made to the question of steam generated per sq. ft. of ground space, and it is interesting to note how engineers are now concentrating their energies in this direction, so as to obtain a large boiler output in a minimum space. A comparison between the Hornsby upright boiler as described and the Stirling boiler about to be installed at the Carville station of the Newcastle Electric Supply Company may be of interest, as both happen to have a normal evaporation of 33,000 lbs. per hour.

	Hornsby.	Stirling.
Normal evaporation per hour, lbs. ...	33,000	33,000
Heating surface, sq. ft.	10,850	6,380
Grate surface, sq. ft.	168	110
Ratio H.S. to G.S.	64·5 : 1	58 : 1
Ground space occupied in sq. ft.	506	286
Normal evaporation per sq. ft. of H.S. per hour in lbs.	3·04	5·17
Normal evaporation per hour per sq. ft. of ground space in lbs.	65	115
Draft in in. of water	—	0·6
Efficiency of boiler	—	75 %

Another boiler with upright tubes, now being placed on the market, which attracted a great deal of attention from engineers at the recent Electrical Exhibition at Olympia, is the "Dávies Water-Tube Boiler," which, with a heating surface of 1,028 sq. ft., has evaporated 6¼ to 7¼ lbs. of water per sq. ft., or about 85 to 100 lbs. per sq. ft. of ground space. Its efficiency is about 80 per cent., and, generally speaking, I think it worthy of the consideration of steam users, as it certainly has a future. Regarding the pumping arrangement, I should like to know the number of lbs. of steam used per pump horse-power with the compound pumps described in the paper, because I recently saw a large boiler-feed pump with triple expansion cylinders which worked with 35 lbs. of steam per pump H.P., whilst a compound pump used 47 lbs.; and I have heard of a Manchester make of pump using only 42 lbs. per pump H.P., so I should be glad to have the author's figures for comparison. The feed-water temperatures on the various stages of working would also be interesting. I quite agree with his arrangement of a primary heater, but I think a closed heater placed between the feed pumps and boilers working in conjunction with exhaust steam from the pumps would have been preferable to heating the water in the tank, as a higher temperature would have been obtained. With regard to the suggested provision for economisers, I can scarcely see how they are to be arranged in the station, for looking at the general arrangement on the plan there hardly seems room for them between the chimney and breeching connection to boiler. Perhaps Mr. Patchell will kindly explain that to us. With regard to the condensers and cooling towers I should also like to ask what percentage of power is taken to work this plant, seeing that there are such a large number of cooling towers, and whether the towers are of the natural draught or fan-driven type. With reference to the generators there is a statement on p. 80 that the 4,000-kilowatt machine is probably the largest machine in the country. I think Mr. Patchell has overlooked the fact that eight 5,500-kilowatt machines have been installed at Lots Road, Chelsea, in connection with the American electrification of the underground railways. Mr. Venning.

Mr. H. C. Anstey: I should like to say a few words with regard to the criticisms that have been made on the boilers installed by my firm at Bow. First, with regard to the evaporation, Mr. Rider referred to the evaporation as being 33,000 lbs. normal. Of course it is 66,000, but, as Mr. Patchell said, they have done 100,000. The question of evaporation and heating surface is one that has not received as much attention as it deserves. I dare say a good many people will remember the now almost classical experiments which were made by Mr. Niclausse on his boiler, in which he measured the amount of steam which was evaporated by each section of the tubes. He found that the first two rows of tubes accounted for about 37 per cent. of the total evaporation of the boiler. Although the upright boiler differs essentially from the Niclausse, we have been able to take some measurements, from which we found that the conclusions which Mr. Niclausse arrived at applied practically in this case. It would take too long to enter into the measure- Mr. Anstey.

Mr. Anstey. ments that were made to arrive at that conclusion, but taking as a low figure that 25 per cent. of the evaporation is done in the first two rows next to the fire, the upright boiler has over 15 per cent. of its heating surface directly exposed to the fire—that is to say in the row of tubes next to the fire and in the row immediately behind it—so that when the boiler is evaporating 100,000 lbs., those rows of tubes account for 25,000 lbs., and the rate of evaporation per sq. ft. of heating surface for those tubes is 8·3. You will observe that the mean evaporation over the whole of the heating surface, when the boiler is evaporating at that rate, is about 4½ lbs. Turning to the horizontal boiler, that boiler has only 8 per cent. of its heating surface in the first two rows. Assuming that the horizontal boiler is able to steam at the same rate per sq. ft. of grate surface as the upright boiler, it would evaporate 37,500 lbs. I do not know that it has evaporated that; Mr. Patchell probably may be able to tell us, but if it has it would be quite a top-rating. In that case it would be 4½ lbs. per sq. ft. of heating surface; but the evaporation per sq. ft. of heating surface of the tubes over the fire would be no less than 14·7, or 77 per cent. greater than in the corresponding tubes in the upright. The rate at which the heating surface over the fire is worked has, I think, a most important bearing upon the durability of the tubes. We know that in some boilers, especially those of the marine type, where they are forced, the tubes are apt to hog or sag and to draw out of the tube-plates, and it is quite possible to construct a boiler in which, while the mean evaporation over the whole heating surface will be low, at the same time the heating surface exposed to the fire will be worked at a dangerous rate. I may say, as emphasising the point, that after 15 months' working the fire rows of tubes in the boilers at Bow are as straight as the day they were first put in, although the boiler has been worked frequently at this rate of 100,000 lbs. Turning to another point which has been referred to by several speakers—the smoke question—I will leave Mr. Patchell to reply with regard to what has been said about mechanical stokers. All I need say is that if Mr. Patchell had thought it was advisable to fit the boilers with mechanical stokers it would have been quite easy to do so. The upright boiler, as you saw on the screen last week, has a very large combustion space—it is no less than 6,000 cub. ft. Those who have had experience in burning liquid fuel will know that the rate of combustion per cub. ft. of space is the one that practically determines whether you will make smoke or not. The same thing applies, though probably in a much less degree, when you are burning coal. When the upright boiler is burning at the rate of 30 lbs. per sq. ft. of grate, it is only burning at the rate of 1·6 lbs. per cub. ft. of combustion space. Taking the horizontal boilers, although they were specially made with high furnaces so that as far as possible smokeless combustion would be insured, they have only 570 cub. ft. of combustion space, and when burning at the rate of 30 lbs. per sq. ft. of grate, the amount burnt per cub. ft. of combustion space is 6·5, or over four times the amount in the upright boiler. The reason is not far to seek, I think. It is well known that when

you heat a hydrocarbon it has a tendency to split up and deposit some of its carbon in a finely divided state. This point is certain, that unless you catch that carbon and burn it up before it touches the comparatively cold surface of the tubes, it is certain to pass away unconsumed. The larger the combustion space the greater the opportunity the liberated carbon has of mixing with the air of combustion and being completely burnt. Several speakers have touched upon the question of floor space. The last speaker, in making a comparison with the Stirling boiler, took the normal evaporation of the upright boiler, but did not take the maximum evaporation. The figure of 100,000 lbs. which Mr. Patchell has given us is done easily, and therefore might almost be considered as a normal evaporation; and referring again to the figures of the evaporation, over the first rows of tubes it will be seen that in the upright boiler this is so moderate as to show that if the draught was there, or if by any means the grate area could be increased, it would be quite safe to run those boilers up to 120,000 or 130,000 lbs. As regards floor space, the double stoking space between the horizontal-tube boilers is 12 ft.; in between the vertical-tube boilers it is a matter of 19 ft. But the horizontal boilers also require a stoking space at the front, and I take it that few people would consider less than 10 ft. satisfactory. So that taking those figures, the amount of evaporation per sq. ft. of floor space, including stoking space, is, in the upright boiler, 86 lbs. per sq. ft., and in the horizontal boiler 54 lbs. There is one other point which I would like to mention, and that is the question of cleanliness. The question of cleanliness has two or three aspects. One is the loss of efficiency as your tubes get dirty, either internally or externally, or both. The horizontal tubes after a short time of working get covered at the top with a coating of dust, and the upper part of the surface is practically useless. In the vertical tubes the dirt falls away from them, collects at the bottom of your furnace, and the tubes remain practically clean. The arrangement of the circulation is such that the back tubes act as economisers. Mr. Booth mentioned in connection with that point that he could not see how they could be; but as a matter of fact the temperature in the back section is less than that due to the temperature of the steam. The water is taken in and made to move in a definite path, and after completely traversing the economiser or feed sections, joins up in the general circulation of the boiler. The result of that arrangement is that the mud is all collected in the bottom of the back headers, and those boilers have been worked for very long periods without stopping to clean. In the boilers at our own works we run regularly for three months without opening up. Then there is another point to be considered in regard to cleanliness, namely, that if a boiler has to be laid off frequently you have, almost invariably, a large expenditure of jointing rings. In the upright boiler we have one joint only to break to examine and clean nineteen tubes, whereas in the horizontal-tube boilers we have two joints to break for each tube. If you have to lay off your boiler frequently for cleaning, you expend a considerable Mr. Anstey.

Mr. Anstey. amount of coal for laying fires and raising steam, and the longer you run your boiler the less is the proportion of the coal so used to that usefully employed in steaming.

Professor Epstein. Professor J. EPSTEIN: As Mr. Highfield referred to the dynamo makers, I should like to make a few remarks. The phenomenon which he mentioned was observed in our laboratory about three years ago, in some special tests we made on the dielectric strength of mica tubes. We observed this bad green colour, and as at the same time we were experimenting with regard to ozone, we recognised the bad odour which we found upon opening the tubes. We took up the question and treated it on broad lines, that is to say, we took for a continuous test a combination of tubes of different manufacture, and filled with copper insulated with different material. Of course it was clear that the action was not a chemical one of an ordinary nature, but that the chemical action was due to the dielectric stress; so last, but not least, we had to combine the different mica tubes filled up with different materials with different dielectric stresses. We hoped to overcome the phenomena in two different ways—either by filling up the tube with some material which might absorb the bad gases, or by giving to the coil in the tube a sort of metal sheath of the same potential, which would take the blue discharges and absorb the bad gases. But when we inspected our tubes at intervals of 1,000 hours, we discovered that the dielectric stresses that we used to have in our machines, applied to the material we used, were a long way from the danger zone. That coincided with some experience we had gained with some 10,000-volt machines which had been running since 1898. I quite agree with Mr. Highfield with regard to the points he mentioned about 3-phase against 2-phase, and I also agree that the Charing Cross Company was quite right at the time, as compared with the Metropolitan Company, when they chose 3-phase and not 2-phase current. We have discussed the question of the phenomena inside the mica tube, but there are other difficulties outside the same, due to the connecting strips between the different coils and between the different tubes. Here the best method is to have a good space, and you will have much more space if you wind your motors for 50 cycles instead of 25. So I should like to say, from the dynamo maker's standpoint, that in this respect also Mr. Patchell has worked on the right line in taking 50 cycles instead of 25.

Mr. Mordey. Mr. W. M. MORDEY: There is a good deal I should like to say on the paper, but I will confine myself to one or two points. I agree with the author and with Professor Epstein as to the choice of 50 $\sim$, because in the first place it makes electric lighting possible by alternate current without the use of rotating converting machinery—but perhaps Mr. Patchell does not want to do that. Secondly, it enables one to use a motor-generator instead of a rotary converter, and that gives for any given variation of primary pressure the least variation of the secondary pressure; and there are other good reasons.

I am glad we have an opportunity of hearing something about Mr. Highfield's experiments and suggestions as to the cause of the deterioration of insulating materials under alternate high pressures.

We need not be surprised that nitrogen oxides should be formed, and nitric acid if moisture is present. We shall hear a good deal about that in the next few years in connection with the making of nitrogen compounds electrically by utilising the nitrogen in the air. But there is another possible action with alternate high pressures that I would like to mention. This example of Mr. Highfield's seems on examination to support the view I have held for some time,* that the action may be mechanical and not chemical or electrical at all, or at least may be partly mechanical. The perishing of the paper is very curious. It is quite rotten; the pattern of the gauze is reproduced on it, a number of little holes being made so that it has become a paper gauze. Some time ago, in trying to account mechanically for the heating that occurs in high-tension alternate-current cables, I came to the conclusion that there was a possible explanation which I would like to mention. It is this: The pressure on the insulating material between two high-tension conductors due to electrostatic attraction may be very considerable. At 10,000 volts and 0·2 in. of insulation it is about half a pound per sq. ft. The attraction is proportional to the pressure squared and inversely as thickness squared. A blow or pressure of about half a pound per sq. ft. applied one hundred times a second for many hours to insulating material would be quite sufficient to account for the paper in Mr. Highfield's experiments being made friable and having the pattern of the gauze reproduced on it. We all know that we can tell whether an insulated high-tension cable is alive or not by simply taking hold of it; we feel a mechanical vibration which, I imagine, is a result of this static attraction. I suggest that these oft-repeated, quite appreciable blows occurring on the comparatively resilient insulating material accounts, to some extent at least, for the deterioration of that material, as well as for the heat developed by the resulting friction. Mr. Mordey.

I will not occupy any more of your time now. This is the sort of paper that makes us realise how very much electrical engineering is becoming ordinary or general engineering, and how the engineering problems in our work are becoming at least as important as the electrical problems. But I do want to say, as I have said more than once before, that we should not lose sight of the very poor results obtained even with the best plant. For example, Mr. Patchell's result of 4 lbs. of coal per unit means an inefficiency of about 94 per cent.—a good result, perhaps, by comparison with others, but, as an example of getting energy out of coal, woefully disappointing, for it means that about 94 per cent. of the energy of the coal is lost in the generating station. This point of view may not at present be a very practical one, but it is one that should not be lost sight of—otherwise we shall not advance. We, as electrical engineers, may at least take credit to ourselves on the fact that of these enormous losses only a small part occurs in the electrical part of the plant.

Mr. H. M. SAYERS: An experience I have had several times goes to confirm Mr. Highfield's view that the trouble due to the silent discharge Mr. Sayers.

* *Minutes of Proc. of Inst. of Civil Engineers*, clix. pp. 225–228, 1904.

Mr. Sayers is a chemical one rather than a mechanical one, although no doubt both effects exist. I have had troublesome faults on the inner "tails" of concentric cables working at 2,000 volts, with the outer earthed. The cables were insulated with vulcanised rubber, and in every case the rubber was within a small fraction of an inch of earthed metal. The rubber was undoubtedly rotten where it failed, which supports the view that the failure was due to an oxide of nitrogen or to ozone, and the effect could be entirely prevented by covering the rubber with a close sheath of lead or other conducting material, or else keeping it at such a distance from all earthed metal that no silent discharge could take place across the gap. On boilers I will only say that mechanical stokers of a correct type would enable Mr. Patchell to burn bituminous coal as well and smokelessly as he burns small Welsh by hand, without interfering with his large steam production. In a particular case where I made some tests on actual working about three years ago, an underfeed stoker, using "washed beans" of a fair bituminous coal, gave an evaporation at and from 212° F. of 10·46 lbs. of water per lb. of dry coal. That was considerably better than was got on the same boilers with hand-firing. I should say that this evaporation includes the equivalent of superheating about 120°; and it also includes the equivalent of heating the feed by an economiser to 171° F. That boiler was able, with ¼-in. water pressure of draught, to burn 31 lbs. of the same coal per sq. ft. of grate surface, so that there is no difficulty in getting the steaming capacity; similar small bituminous coal could be delivered in London at a considerably lower price than small Welsh. Mr. Patchell has discarded the use of surface condensers because of the difficulties he has found in other cases from dirty tubes. I understand he means scaling of the tubes. I have met with the same difficulty; the cause of it is pretty obvious. It very rarely occurs with a natural condensing water, although I have known one very bad case where canal water was used. There the condenser tubes were removed every three months and treated to a bath of dilute hydrochloric acid, which is the simplest way of cleaning tubes in that condition, and does not damage brass or copper. When this trouble has occurred elsewhere it has been where cooling towers are used. Passing the circulating water through a condenser and cooling tower over and over again, the evaporation leads to a concentration of salts in the water, which by and by may become a saturated solution. If it approaches saturation with carbonate of lime, the condenser tubes will scale. The remedy is to soften the make-up water according to the amount of its hardness. It is not necessary to soften the circulating water below 10 or 12 degrees of hardness; if it does not exceed that, scaling will not take place in condensers. There is another tributary cause. Concrete reservoirs are very often used under the cooling towers. The water, dropping through the cooling towers and coming in contact with large quantities of air, absorbs carbonic acid, and when in the tank it dissolves the carbonate of lime from the concrete, and so hardens itself that it may be much harder after a few passages than it would have been from the simple concentrating effect. In London, or

Mr. Sayers.

in other towns where there is a great deal of coal smoke, the water picks up other substances besides carbonic acid. In London rain water contains about two parts per hundred thousand of sulphuric acid, in Manchester between four and five parts, and in Glasgow eight parts; so that not only temporary hardness from the carbonic acid, but permanent hardness from the sulphuric acid, may be derived from cooling towers with concrete reservoirs. The remedy is perfectly well known. Milk of lime cures the carbonic acid hardness, and a little caustic soda will neutralise the sulphuric acid. Taking these precautions, the condenser tubes will not scale, and one gets the advantage of surface condensing with only sufficient fresh water to make up for the evaporation. Resonance troubles are mentioned in the paper. I once had a very sad experience of them. I was in charge of over one hundred miles of alternating high-tension mains. They were not in good condition, and the cables used to fail in a dozen places at a time. It puzzled me, until I noticed that it always took place during the hours of light load. We were obliged during the hours of light load to run two sets, because the magnetising current was a little too much for one. The power-factor was low, and, to economise as far as possible, the sets were run at low speed. The normal frequency of the system was 83, and we used to run down to about 65. I made a rough calculation, giving probable values to the capacity and self-induction, and found that there was a great probability of getting resonance somewhere about 60 to 65. I therefore took care that during the hours of light load the periodicity should be at least 70 to 75, and those wholesale cable troubles ceased from that day onward. Mr. Patchell's little trouble with his spark-gap resistance is no doubt due to the water dissolving small quantities of sodium salts from the glaze of the earthenware. I believe he could get a hard glass which would not yield any such salts, but probably the better way is to use a weak solution of some salt, such as chloride of sodium, which will not change much. I should like to ask Mr. Patchell if he has tried a long lamp filament sealed in a tube. It should be easy to obtain a filament of several thousand ohms resistance and of such diameter that the discharge current would be insufficient to damage it. An unflashed filament would probably be best.

Discussion at Meeting of January 11, 1906.

Mr Fynn.

Mr. V. A. Fynn: I should like to say a few words with regard to the breakdown of the armature insulation of high-tension alternators referred to by Mr. Patchell. His view is, that when nitric acid is formed within the insulating tubes it is probably due to impurities of the insulating material. Mr. Highfield puts down the formation of this acid to the silent discharge alone and the ozone generated by this discharge; he thinks that an amount of nitric acid is formed in this way which is sufficient to destroy entirely the insulation of the armature conductors in a very short time indeed. These two views differ very widely, and, for the sake of the rapid development of high-tension plant, I most sincerely hope that Mr. Patchell's view will prove to be the correct one. It is true that Mr. Highfield has proposed remedies,

Mr. Fynn. but these, even if they really answer their purpose, only put greater difficulties in the way of the manufacturer. Personally I think that impurities in the insulating material are, in the main, responsible for the formation of the various acids which have been discovered, and which occasionally destroy the insulation of the conductors. When I talk of impurities, I do not wish to cast an aspersion on any maker; we are now confronted with a novel and quite unexpected difficulty, and I feel that it would be quite unfair to expect anybody to provide against such contingencies. It simply appears to me that some of the insulating materials, which have been universally recognised as excellent for all practical purposes, fail when used in conjunction with the extra high voltages now often called for. I believe that the process by which the various acids are formed is a very complicated one and can hardly be fully predetermined, but I think that during the operation of a machine any unattached or incompletely attached acids which are present in the insulating material are set free and are absorbed, destroying the covering and attacking the conductors. The influences which help to release these acids are, first of all, the heat imparted to the insulating tubes by the armature laminations and by the armature copper, the temperature of which, of course, is raised considerably during the working of the machine; also the heat generated in the tubes owing to the stress imposed on them through their being subjected to a very high difference of potential. It is also probable that the silent discharge contributes in a small degree to the formation or liberation of these acids, and that a damp atmosphere materially furthers this process. I purposely say acids, because although nitric acid seems to be, in some cases, the predominant partner, other acids are always present in varying quantities. It is very difficult to say which material forming part of a tube is responsible for the damage, and it can only be discovered by a process of elimination; personally I suspect that the solvents made use of to dissolve the shellac, which is generally used, are the most prominent offenders. Now as to the test upon which Mr. Highfield bases his theory, it seems to me he only reproduced the exact conditions which prevailed in the faulty machine, and I venture to say that his test is quite inadequate to prove anything beyond the fact that the combination of tubes composed of certain materials with conductors raised to a high alternating potential is responsible for the production of a number of acids, amongst which nitric acid is most conspicuous. If Mr. Highfield had made comparative tests with a number of tubes, all composed of different materials, having approximately the same dielectric strength and the same opening (one of these tubes might, for instance, be a glass tube), and had obtained uniform results in all cases, then I could have endorsed his conclusions, but, failing such conclusive tests, I incline to think that Mr. Patchell's view more nearly approximates to the true facts of the case.

Mr. Campbell Swinton. Mr. A. A. Campbell Swinton: I only wish to address the meeting on a single point—one which appears to me to be much the most important matter connected with this interesting paper—and that is

Mr. Campbell Swinton.

the fact that almost the whole of the machinery described is of foreign origin. I also wish to bring to the notice of the meeting what appears to me to be the totally inadequate reason that Mr. Patchell gives for this being so. He states that, "as regards the type of plant to be adopted, it was felt that the load would grow so rapidly that no risk could be run with experiments, and the author, therefore, felt compelled to adopt such types of plant as could be seen in satisfactory work." There are various reasons why the orders for plant for use in this country go abroad. One of the most common reasons is because the capital comes from abroad, and the people who find the money naturally stipulate where their own money is to be spent. I do not think that is a reason we can complain of, but I take it there was no such reason in this case; I take it that it was purely a matter of English money, and it was purely a matter in the discretion of the engineers and the directors of this company whether they should buy their plant in this country or in other countries, and the only reason for going abroad is comprised in the sentence I have read. I should like to know what some of the older engineers of this country, such men as Watt, Stephenson, and Brunel would have thought of the suggestion that in order to avoid a little experimenting they should go and place their orders abroad. I do not believe for a moment they would have hesitated to have kept the work at home and run some little risk. I think that in the general interest of the country engineers and also shareholders should be prepared to run some little risk. I personally have no interest whatever in any British electrical manufacturing company, and therefore I have thought that perhaps I was a suitable person to raise this question. Manufacturers can be taunted with the fact that they are interested, but personally I have no interest in the question at all. This tendency to order machinery abroad when it can be obtained at home may, perhaps, denote prudence, but it certainly does not show any courage. I have no other point to bring forward, but in conclusion I can only suggest that this generating station, if it was only more portable, and if it could be carried round the country, would be a most apt illustration of what might be advantageously avoided by a suitable measure of Tariff Reform.

Mr. Wilson.

Mr. D. WILSON: As a former central station engineer I have read this paper with very great interest, and join with other speakers in expressing regret that Mr. Patchell did not see his way to give some figures which would enable us to believe that this station was really economical, instead of allowing us to judge, perhaps incorrectly, on the vagueness of the figures given, that it is not so efficient as some of the older existing stations. It is to the boiler question, however, that I have directed my attention more particularly, and I would like to say something in reference to a few of the points raised by the previous speakers, more especially with reference to horizontal and vertical boilers. It is, of course, well known that there is no water-tube boiler with truly horizontal tubes. In the Babcock boiler the inclination is 15°, and after some thirty years' experience we are still convinced that this angle is all that is necessary to produce the results

Mr. Wilson. required, namely, to establish a full and definite circulation. It has been suggested that in the vertical tube boiler no soot or scale adheres to the tubes. That suggestion is, of course, absurd, and is one that will not stand investigation, and with reference to that point we cannot have a better example than a Green's economiser. We all know that it is necessary to have an external scraper to keep the tubes free from deposit, and we also know that it is necessary to clean the tubes internally from time to time. With reference to the evaporative capacity of Mr. Patchell's boiler, there is, of course, no difficulty in designing a boiler to give 100,000 lbs. evaporation. It is not in the arrangement of the heating surface that the difficulty lies; it is in the design of the grate, and the problem resolves itself into a question of the practical working of the furnace. In our opinion a boiler of 100,000 lbs. evaporation is wrong, and from our experience in the design of large central stations we think the limit is about 30,000 lbs., when everything is taken into consideration, such as minimum capital outlay on spare plant, facilities for cleaning and inspection, efficient stoking, capacity of plant put out of commission from any cause, etc. Even with a 30,000-lb. boiler it is necessary for firing to have at least one door open almost continuously, and the disadvantage of this is obvious. With regard to the question of the furnace design, I should like to make a few remarks in reply to a statement made by a previous speaker with reference to the height of the combustion chamber in the so-called triangular furnace. This is, I think, very much overrated. There is a limit in both ways to the furnace, and it is just as possible to have too large a furnace as it is to have one too small. Sufficient combustion space is essential, but there is no object in increasing the height beyond what is necessary for a proper mixing of the gases and perfect combustion, and I am sure there are several central-station engineers present who will confirm the fact that perfect combustion is obtained in an ordinary horizontal tube boiler. In connection with this point, some very elaborate tests have recently been carried out at the Islington Corporation Station, and in one test of twenty-four hours' duration, the boiler and superheater working at a full load gave an efficiency of 79·6, and the cost of evaporation, which is a more important point from a commercial point of view, came out at slightly under 5s. per thousand gallons. This result was obtained with absolute smokelessness throughout the test, although the coal contained over 30 per cent. volatile matter, and I think it conclusively proves that the horizontal boiler has a high efficiency, and that the combustion space is sufficient. As far as evaporation per square foot of heating surface is concerned, the figure suggested by Mr. Anstey is exceeded every day with the horizontal tube boiler, and it may be of interest to you to know that in the Navy we have to evaporate from 8 to 10 lbs. per square foot of heating surface during the full-load trials, and that that is done without any damage to the boiler or any serious reduction in the economy. As regards the floor space, I think probably too much importance is attached to this question. Mere calculations of pounds per square foot is not the whole story, and one can cram the space at the

expense of other important considerations. The station of 15,000-k.w. capacity recently put up in Paris for the Metropolitan Company approaches the ideal nearer than any other, and the size of the power-house is only 123 ft. by 66 ft. I do not think I have anything else to say, beyond expressing a wish that Mr. Patchell will supplement his paper by giving further figures. His station is one of the most modern reciprocating plants in the country, and it would be of the greatest interest to the Institution and engineers generally if we were enabled, by means of his figures, to make a comparison between this station and some of the modern turbine installations. Mr. Wilson.

Mr. A. H. SHAW: There is one point I should like to raise with regard to the use of large tubular boilers. When one has to deal with large generating sets up to 5,000-k.w. capacity, I am not at all sure that it is an advantage to adopt such large boilers as Mr. Patchell describes. All boilers require shutting down occasionally or periodically for the purpose of cleaning and inspection purposes, and if these large generating sets are supplied by one boiler or two boilers with a common grate, as described by Mr. Patchell, when the boiler is shut down for cleaning or other purposes the generating set must be thrown out of commission as well, whereas if we adopt a battery of boilers to supply each generating set, as in the Carville Station, one boiler can be shut down at any time without interfering with the others, and without interfering with the running of the set. Of course the capital cost may be somewhat increased by adopting a battery of boilers, but I think it would be more than compensated for by the advantage of being able to run each generating set for a very much greater period than would be the case if it is supplied by one boiler. Two or three speakers have referred to the periodicity, and have stated that a periodicity of 25 would have been more suitable as motor generators or rotaries have to be used. I know it has been generally held by engineers that a periodicity of 25 is not suitable for incandescent lighting, but I remember seeing a few weeks since that over 18,000 16-c.p. lamps are now being supplied in Buffalo by 25-cycle alternating current from Niagara Falls, static step-down transformers only being used. I do not know whether this refers to the paper, but I should like to know if that is a fact. If they can use a periodicity of 25 for lighting on the other side of the Atlantic, why should we not be able to do so here if it is required in any particular case? With regard to the condensers, I quite appreciate Mr. Patchell's desire to avoid surface condensers, as I have had the same trouble in cleaning that he has had. I have also found that the only real method of cleaning a condenser in use with cooling towers is by means of a solution of hydrochloric acid, a point which Mr. Sayers referred to, although I do not go so far as to take out all the tubes and give them a bath every three months. I think that must be rather a costly proceeding, and it might perhaps be preferable to leave all the tubes out and turn the condenser into a jet condenser at once. I think the only real method, as Mr. Sayers stated, is to treat your make-up water, although that also is rather a costly proceeding. I very much hope that Mr. Patchell, in his reply, will give us some Mr. Shaw.

Mr. Shaw. figures with regard to the steam consumption for his engines, because a figure of under 4 lbs. is rather vague, and I have known that figure reached in a very much smaller station, using small Welsh.

Mr. Boot. Mr. H. L. BOOT: I think Mr. Patchell is quite right in avoiding economisers in the design of his station. I have found myself that if plenty of heating surface is put in, that is, plenty of tubes in the boilers, and superheaters as well, there is very little extra gain by putting in economisers; in fact, on boilers which we are running now with tubes we find that when we are running multitubular boilers the gain in feed temperature is 100° less than what it is when we are running Lancashire boilers. When the extra cost of the flues and superheaters, and also of the economisers, is capitalised, it will appear a very doubtful question, considering the matter from the point of view of cost, as to whether it is worth while going to the extra expense and taking up the extra space for economisers where superheaters, multitubular boilers, etc., are used. Undoubtedly with Lancashire boilers there is a great gain in spite of the extra capital cost. I was surprised to hear Mr. Patchell say that he experienced trouble in keeping the condensers clean. I think probably this may have been due in his installation to allowing the cooling water to get to too high a temperature. If he had kept his cooling water at a lower temperature, he would probably have found that the tubes kept clean very much longer. However, as another speaker has suggested, these tubes are not at all difficult to clean with a bath of dilute acid. I would like to ask Mr. Patchell if he will kindly state in his reply, if possible, the capital cost of the kilowatt caused on account of the additional mains required by placing the station some distance out from the area of supply—that is to say, I want to see the capital cost of all the items put down separately, and of course added together showing the total cost, to see when we come to the position where the cost of the mains is equal, or considerably more than the gain obtained by placing the station nearer, especially when using underground mains and the system he proposes.

Mr. Walker. Mr. J. R. WALKER: I have been very much interested in the part of the paper relating to the boilers installed at Bow. I am of the same opinion as Mr. Patchell regarding the use of large steam-raising units, and am much pleased to see that the adoption of such large water-tube boilers has been a success. I have had considerable experience with large boilers at sea, and have never found any difficulty in running them for considerable periods; in fact, the boilers were the last place in which we expected to find trouble. The size of boilers with which I have had most experience has been from 2,000 I.H.P. up to 3,500 I.H.P. each. I do not, however, think that the way the boilers are treated at Bow is quite right, or that the treatment is such as one would expect to be meted out to them after proving such good friends to Mr. Patchell when he wants an extra pound or two of water evaporated. I find on reading the description of the boilers that they are expected to act as water-heaters or economisers and also as water purifiers, in addition to what I take to be

Mr. Walker.

the original purpose of a boiler—that is, steam generation. We are told on page 73: "The back sections act as water-heaters or economisers with a definite circulation; any scale or sediment is deposited in them, and the front sections kept quite clean." I must say that I am decidedly of opinion that any boiler, more particularly a good boiler, such as this upright boiler has proved to be, is the very last place in which water purification should be attempted. I have no particulars as to the quality of the water supplied by the artesian wells at Bow, but I should think that Mr. Patchell has been very fortunate indeed if he finds that the water contains neither temporary nor permanent hardness. According to the paper there is no water-softening plant put down, so that there is evidently very little temporary or permanent hardness. If we take it that the back sections act as purifiers, then I am of the opinion that the quantity of impurities present in the water would have to be very slight in order that the action should be completed in the back sections alone. My experience of water purification in connection with feed-water for boilers has been that the trouble has been not so much to purify the water from matters in solution as to get rid of the impurities when they reach the solid state. I have found that it is generally necessary to have a filter or plenty of tank space in which the water can stand until the suspended matter settles. For this reason I do not think the action of the purifier part of the Hornsby boiler can be completed there, as the time for settlement or deposit is so short, and I feel quite sure that a good deal of the deposit, however little it may be, is very likely to be carried into hotter parts of the boiler. Further, as we are told that the back sections act as a water-heater, I think it is too much to expect that any kind of sediment would be deposited there. The temperature in this section would, I am afraid, not be high enough to cause any sulphate of lime, or any of the other compounds which cause permanent hardness in water, to be deposited there. As is well known, the impurities referred to are only deposited at high temperatures, such as would be found in the front sections of the boiler, and I am therefore much interested in seeing by Mr. Patchell's paper that he has evidently found a water containing no permanent hardness when he states that the front sections are kept quite clean. I have had considerable experience in running boilers, and I must congratulate Mr. Patchell on being able to keep any of his tubes clean. At the last meeting a gentleman who spoke in favour of the Hornsby boilers stated, as showing the cleanly habits of the upright Hornsby boiler, that it could be run for three months without cleaning. I do not think that that is anything but a very moderate performance, as I have, using water of 15° hardness, treated with a home-made water softener, run horizontal water-tube boilers for a period of six months without internal cleaning, and at the end of that period I found there was very little scale present. That shows the value of having even a home-made water-softener. Of course, it may be that in the case of the boiler described in the paper it is on account of the purifier part of the apparatus becoming dirty that the boiler is shut down for cleaning.

Mr. Walker.

If the front sections have to do all the steam raising, and raise as much steam as Mr. Patchell says they do, then I think it is a very shabby way to treat them to stop them from working while he cleans out the purifier part. If this is so, then the sooner Mr. Patchell carries out the purification of his feed-water in a purifier apart from the boiler the sooner he will get the continued use of his boilers proper. I am of opinion that no stone should be left unturned in order that the full value of the boiler can be continuously obtained. We hear it stated on many hands that water that is too pure should not be put into boilers ; but if proper precautions are taken in the way of keeping the alkalinity of the boiler water at a safe value, and by the judicious application of zinc plates—(these will no doubt appeal to electrical engineers, as they are supposed to form an electro-couple with the plates forming the boiler)—I think, if these precautions are taken, very little trouble will be found in running boilers with water, and water alone. During the experience which I have had in running boilers at sea, using the same water over and over again, and with a make-up consisting of nothing but evaporated sea-water, I have never seen any ill-effects due to the water being too pure, and no difficulty was found in running the boilers for long periods. I feel sure that any action which is taken by central station engineers towards supplying their boilers with pure water will be amply repaid by the increased length of time it will be possible to run the boilers without shutting down for cleaning. There is a great deal said about the relative benefits to be obtained from vertical tubes and horizontal tubes ; we have had some opinions expressed on that subject to-night. We are told by the makers of water-tube boilers, or by their representatives, that when we use vertical tube boilers the tubes run very clean. I have had very little experience of vertical tubes, but the little I have had has led me to have doubts as to the truth of all the assertions made in regard to the matter. There is nothing like a practical illustration, and I have here in my hand a section cut from a nearly vertical tube. The boiler was run at 140 lbs. per square inch, and the only treatment meted out to the feed-water was the addition of a boiler composition. You will see the result of adding boiler composition to the feed-water. (Specimen produced.) I am inclined to believe that, with scale-forming water, the vertical tube is not so much in front of the horizontal as some people would like us to believe. I think that is all I have to say on the matter of boilers, but I have a question or two to ask Mr. Patchell—he has been asked a few already. We are told on page 75 of the paper that the method of pumping adopted is the air-lift system. I have been told, or have read somewhere, that when water is raised by means of an air-lift a difficulty is experienced in the boiler, into which the water is fed, through the air which is used to raise the water becoming intimately mixed with the water, being pumped into the boiler, and thereby causing corrosion of the plates. I would like Mr. Patchell to tell us in his answer to the discussion whether he has had any trouble whatever in that connection, due to air being taken into the boiler and so causing corrosion. Then I have another question, on which I

should like to receive some information. Will Mr. Patchell tell us what percentage of CO_2 is present in the flue gases of the upright boilers when only one grate is being used? If we get a figure showing us that, I think we may then have some clue as to why the consumption of coal approaches 4 lbs. per unit generated. My last question is, Will Mr. Patchell tell us what staff he requires in each of the departments of his generating station? We hear so much at the present day of the labour-saving properties of turbine-driven sets and mechanical stokers that I should like very much to know how many men Mr. Patchell required at Bow, so that we could make a comparison with some of the newer stations which are driven by turbine machinery and use mechanical stokers; and then we will really see what the labour-saving properties connected with these particular classes of machinery amount to. Mr. Walker.

Mr. W. DUDDELL: There are two points in Mr. Patchell's paper to which I should like to refer. The first is the destruction of the insulation of the stator coils which has been observed by Mr. Highfield, and of which Mr. Patchell has found no trace. There seems no doubt, from what Mr. Highfield has told us, that the prime cause of the destruction is one of the oxides of nitrogen. It is of great interest to inquire what conditions govern the production of these oxides of nitrogen in order to form an idea why these effects have only been observed in some cases and not in others. The oxides of nitrogen are always produced when a brush discharge takes place in air. A brush discharge will take place if the potential gradient exceeds a certain limiting value; according to a recent paper by A. Russell air breaks down and a discharge takes place if the potential gradient exceeds 38,000 volts per cm. Mr. Duddell.

Fig. A represents purely diagrammatically a single conductor, the adjoining wall of the mica tube and the iron frame of the machine. The frame of the machine is assumed at zero potential, and the ordinate CC′ represents the potential of the wire above the iron frame. The ordinates of the curve AB′C′ represent the potential at any point in the dielectric. The maximum potential gradient in the air part will be at C next the surface of the wire, that is, the curve is steepest at this point. If this potential gradient exceeds the limit for air, a brush discharge will take place with the formation of greater or less quantities of the nitrogen compounds. The maximum potential gradient and the shape of the curve AB′C′ depend

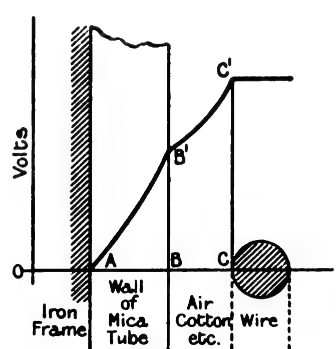


FIG. A.

chiefly on: The difference of potential CC′ between the wire and the frame; the thicknesses of the air cotton, etc., and of the mica wall; the radius of the wire and of the mica, etc., if curved; the specific

Mr. Duddell.

inductive capacities; and the conductivities of the two media between AB and BC.

In Mr. Patchell's 3-phase, 10,000-volt machines, earthed neutral, the maximum P.D. CC' is about 8,200 volts, whereas in Mr. Highfield's 2-phase, 10,000-volt machines it is about 14,100 volts. At first sight this seems like the explanation of the difference. It cannot, however, be the whole explanation as, if I understood Mr. Highfield correctly, he has observed the destruction of the insulation in coils in which the P.D. between the wire and the frame was only 2,000 R.M.S. volts. So that Mr. Highfield has noticed deterioration with only 3,000 maximum volts between wire and frame, and Mr. Patchell has not found it with 8,200 volts. Of the relative thicknesses of the mica wall AB and the air cotton layer BC in the two cases we have no information, but it is probably very similar, as it is determined by questions of dielectric and mechanical strength. The radius of curvature of the wire at the corners is smaller in the Highfield machine, judging by the rectangular tube he showed at the last meeting, which would greatly increase the potential gradient and destruction at the corners, as was well shown in the test exhibited. It remains, however, that in the relative specific inductive capacities and conductivities of the two media the greatest differences may exist.

To reduce the potential gradient near the wire is a problem similar to that considered by Mr. O'Gorman in his paper on cables before this Institution in 1901, and the method he proposed was called "grading" the dielectric, which consists in arranging the conductivity and specific inductive capacity so as to obtain the required distribution of the potential through the dielectric. In the present case we require to concentrate the stress on the wall AB, that is, to raise the point B' in Fig. 1 so as to relieve the air and cotton of as much stress as possible. If the material of the wall AB is fixed, this can be done by increasing the specific inductive capacity and the conductivity of the layer BC. Thus it seems that a bad insulating material for BC would give better results. By bad insulating material I only mean one that insulates badly, and not one which contains acid, etc.

It is to be noted that the high specific inductive capacity of mica and shellac are unfavourable to their use for the wall AB as they lower the point B'.

There are two other methods by which this difficulty may be overcome, one of which is fairly self-evident, namely, to impregnate the coil so as to exclude the air altogether. The second method was mentioned by Professor Epstein at the last meeting, and consists in placing a metallic shield between the wire and the mica tube. It seems to me that this method should give excellent results, provided that the metal shield is connected electrically to the coil, and that the mica tube is built up on the metal shield so as to exclude all air from between the metal and the mica. It is probable that the shield would have to be thin and of high resistance material to prevent eddy-current losses in it.

The second matter to which I wish to refer is the question of switching on and off of cables.

Mr. Duddell.

Mr. Sparks, in opening the discussion on the paper, mentioned that I had carried out many switching tests for him, and he has kindly given me permission to show you some of the results obtained. The conditions which prevail on switching in and out apparatus differ so much from one station to another, that I only propose to refer to two points. One is the difference between the break in air and the break under oil on disconnecting an unloaded cable, and the second is the effect of a transformer connected to the cable. The feeders used for the tests were 6,000-volt rubber cables, and the tests were all carried out at 2,000 R.M.S. volts to avoid any risks to them. The alternator gave a very square-topped P.D. wave-form, which was further distorted by the capacity, as will be seen in the following figures. I may mention

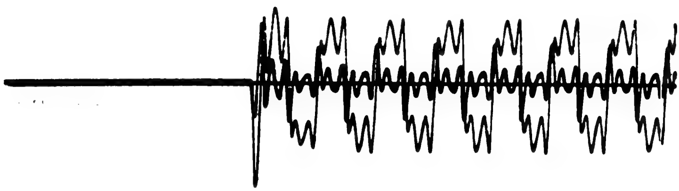


FIG. B.

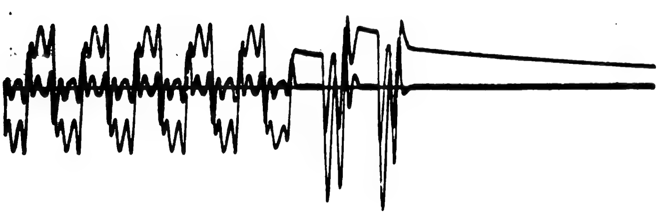


FIG. C.

that, as the result of these and other tests made on the machines, the pole-tips were redesigned, and the wave-form made almost sinusoidal. In all cases the larger curve is the P.D. curve, and the inner smaller curve the current. For all the P.D. curves 1 mm. = 300 volts, for the current curves in Figs. B and C, 1 mm. = 2 amperes, and in the rest 1 mm. = 4 amperes. The tests were all carried out single-phase to simplify results. The rises do not, of course, occur at every operation of the switch. It is therefore necessary to make a large number of tests to find out what may occur.

Figs. B and C show switching on and off of about 4½ miles of cable on open circuit, using brass contacts in air. Fig. B is typical of the sudden instantaneous rise in P.D. which occurs on switching on a feeder or open circuit; the maximum volts recorded is 4,200, or 2·1 times the R.M.S.; this is quite a normal case. The switch-off, Fig. C, is a bad one, sparking having taken place at the contacts, the maximum volts rising to 5,100, or 2·55 times the R.M.S. value. Fig. D is a switch-on of twice the length of cable using brass contacts in air; the rise is

Mr. Duddell.

to 4,500 volts, or 2·25 times the R.M.S. value. Switching off this same length of cable with *contacts under oil, no rise at all* is obtained in Fig. E.

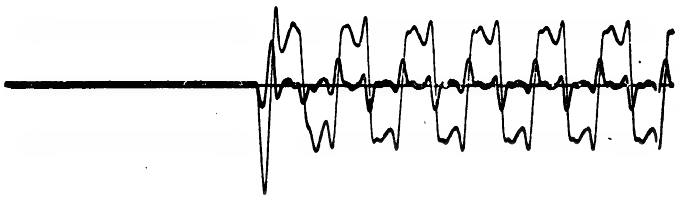


FIG. D.

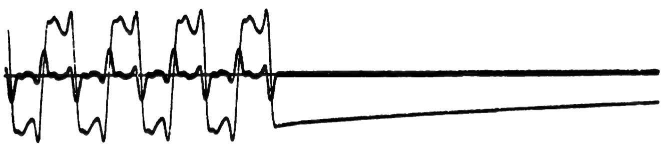


FIG. E.

Mr. Highfield in his remarks referred to the fact that he has his instrument transformers connected across his mains when he switches in. I do not think that they tend appreciably to prevent the rises. To illustrate this point, the test shown in Figs. D and E was repeated with a 400-k.w. transformer on open circuit connected to the far end

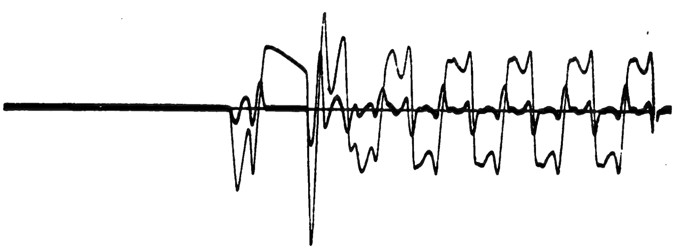


FIG. F.

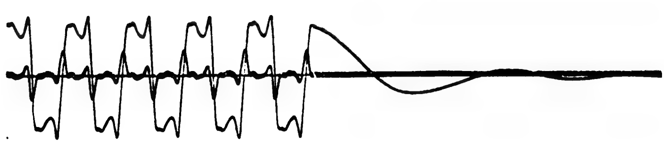


FIG. G.

of the cable; the results, Figs. F and G, show a rise at switching on of 5,400 volts, or 2·7 times the R.M.S. value. At the switch-off with the break under oil there was no rise. If, however, the transformer has its secondary closed on a low resistance, or if it is heavily loaded,

then when it is switched on with the cable it will tend to reduce the rises. It is of interest to compare the way the voltage dies away on the cable after switching off. In the first case, Fig. E, we have the cable discharging through a non-inductive leak (the oscillograph), and in the second, Fig. G, through the inductive transformer giving slow oscillations which are quickly damped out. In conclusion, I may say that these results obtained with Mr. Sparks's plant are quite typical of the records I have obtained in many other cases I have investigated. Mr. Duddell.

Mr. G. WÜTHRICH, Oerlikon (*communicated*): With reference to Mr. Patchell's remarks as to the non-existence of any trace of nitric acid on the stator coils of his high-tension motors, I certainly think that no modern manufacturer would be so imprudent as to use varnish or other insulating material for which no guarantees have been received from the makers as to total absence of acid, or of any other injurious substance. Most makers of high-tension machinery get these guarantees verified by their own chemists. I strongly believe that everybody who has built high-tension motors for pressures above 5,000 volts, will have to pay the penalty for not having properly appreciated the necessity of investigating the actual causes of the deterioration of the insulation of the high-tension coils. That nitric acid is the enemy we have to battle with is, according to my opinion, beyond a doubt. Mr. Wüthrich.

The study of cable effects, etc., caused me on several occasions to open high-tension coils of induction motors which had been running for the last four or five years. A decrease in the quality of the insulation of the individual wires could be observed. Discoloured spots in the insulation showed plainly that another influence than age only was at work, and chemical analysis proved beyond doubt that nitric acid was the agent. I made this observation some considerable time back, and in order not to have to bear the rather serious consequences I took, and I am still taking, energetic steps to avoid the necessity of having to re-wind at least the commencing coils of the three phases (star-connected) of some of the high-tension motors, and I may say that the very steps which helped me to suppress and even to eliminate the possibility of such breakdowns, are also adopted when constructing new motors, and in both cases the results were eminently satisfactory.

Everybody who has dealt with high-tension motors must have observed more or less pronounced brush discharges, particularly during the pressure tests carried out with a voltage of often twice or three times the working pressure, or even higher. These brush discharges, although practically unnoticeable at the normal working pressure, exist nevertheless, though in a greatly diminished measure, and it stands to reason that the less this brush discharge is observable, the longer it will take to deteriorate the insulation of the individual wires through the formation of nitric acid. The current used to carry out the above-mentioned pressure tests can of course be measured, and if the former is drawn up in a system of co-ordinates as a function of the voltage from zero to maximum, the curve, Fig. H, is the result.

Mr. Wüthrich.

This curve is obviously very important. As a matter of fact I would call it the "life curve" for high-tension machinery in so far as its age is limited by the action referred to. Designers should have no difficulty in making an empirical formula in which the current for a given voltage could be calculated as a function, say, of the total surface of all the conductors in the stator, the voltage, dimensions of insulation tubes, etc.

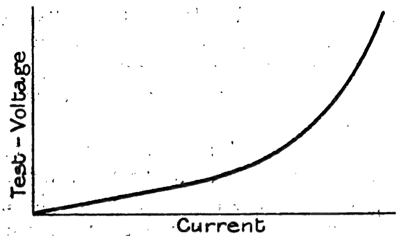


FIG. H.

I think that manufacturers should pass no motors from the test-room which show a higher test-pressure current than that empirically found as giving sufficient guarantee for a reasonably long age of the machines. The Oerlikon Company has been very successful in eliminating the danger of this formation of nitric acid as a result of their extensive investigations. Perhaps a little far-fetched proof of the correctness of my statement as to the existence of the "nitric acid danger" is offered by the action of an English company in Norway. It may have been noticed that according to statements in the press this company commands working capital of about £400,000, and manufactures nitric acid on a principle similar to that which is destroying high-tension motors—if no adequate precautions are taken to suppress it! I do not think that this company is throwing money away.

Mr. Pooley.

Mr. F. POOLEY (*communicated*): The part of this paper in which I am personally interested is that of the cables, and I notice that Mr. Patchell states that the only serious breakdown which has occurred was due to the over-baking of the cables in order to give them a high insulation resistance. I think that it was fully realised some considerable time before the date when these cables were made, that it was not the insulation resistance that formed the most valuable property of high-tension paper cables, but the dielectric strength. It is a curious fact that in paper cables a high insulation resistance is never found with a high dielectric strength, and it therefore seems extraordinary that a firm capable of carrying out a contract of this size should actually endeavour to obtain a high insulation resistance when it could only be done at the expense of the very much more valuable property of high dielectric strength.

Mr. Patchell's immunity from faults on these cables is probably largely due to the great thickness of dielectric which they possess. Cables for extra high tension, built on the old Board of Trade rule for high-pressure work (up to 3,000 volts) of one-tenth of an inch per 2,000 volts, have a factor of safety very much higher than is generally realised. This was brought clearly to my notice some years ago when testing about 77 miles of high-tension 3-phase cable built to the same rule for 6,500 volts. The test-pressure for these cables was 20,000 volts for an hour, and in no single instance throughout the whole of

that 77 miles could the cables be broken down with, not only that pressure, but the highest pressure available at the time of testing, which was between 70,000 and 80,000 volts, or considerably over ten times the working pressure of the cables. I have no doubt that, had the higher pressures been obtainable, the cables would still have stood. With one fairly long length having a high electrostatic capacity I endeavoured to break down the insulation by means of the rise in pressure due to resonance by switching the high-tension current on and off the cables many times in succession. The only effect of doing this was to cause the cable at the far end from that at which the pressure was applied to spark over from one core to the other. This shows that we have a very large margin on which to work, and explains very largely why these charging devices, of which we heard so much when extra high-tension work first came into vogue in this country, are never used, although installed in most extra high-tension stations. Mr. Pooley.

I think it would be interesting if some experiments could be carried out to discover to what actual pressure the current does rise in a cable on switching in a long length having a high electrostatic capacity, and it seems to me that the reason this sudden rise is not more destructive to the dielectric is that the actual rise is really half a cycle at an enormously high frequency.

I may be quite wrong in this suggestion, but we know from the application of high-frequency currents, as shown by Tesla and others, to medical science, that the disruptive power of these very high-frequency currents is practically negligible. I have not the opportunity at the present time for investigating this myself, but I give it as a suggestion which might be followed up, I think, with advantage.

Mr. J. S. HIGHFIELD (*communicated*): I wish to enlarge a little on what I said in connection with the advantages of 3-phase as compared with a 2-phase supply. One of the chief reasons that 2-phase was adopted by the Metropolitan Company was in order that single-phase current could be conveniently distributed, and, if this is essential, 2-phase has immediately a great advantage over 3-phase, but if the nature of the current distributed is not important, then, for a given pressure to earth, 3-phase supply has an advantage over both single-phase and 2-phase where one of the poles of the latter system is earthed; if, however, all the poles are insulated, and only the neutral point of the winding is grounded—*i.e.*, in the case of single-phase and 2-phase, a point half way down the winding is earthed: then, for a given pressure to earth, both single-phase and 2-phase, and also 3-phase, are all on the same footing and use the same weight of copper. It would be quite simple to use a 2-core cable for supplying single-phase current, which would show just the same cost as a 3-phase cable; in fact, the cost would be somewhat less, as the labour in construction would be less, since only two cores have to be insulated, but the advantage of grounding one pole and having single-pole switchgear throughout is so great that I doubt, unless extremely high pressures have to be used, that a concentric cable with the outer earthed will always score over two insulated poles. Mr. Highfield.

In connection with the nitric acid question, it is to be hoped that

Mr. Highfield.

some one with ample time at his disposal will thoroughly investigate this matter, but meanwhile, in view of Mr. Patchell's further remarks, I am afraid that in my previous statement I have not made the matter quite clear, and I wish to add further to what I then said.

So far as one could ascertain, the coils, as sent out, were dry. They were, of course, tested at the works, and the machines were very carefully dried many days before being worked up to full voltage. The drying was, of course, not carried out by means of fire buckets, but by heating electrically. The machines then worked for a long period—in fact, for two years—without trouble; but after one or two breakdowns, the investigations already referred to were carried out after the green deposit was found. The whole of the materials, I should again repeat, were tested independently both on behalf of the Metropolitan Company and the makers, and they were found to be the best of their kind. The deposit occurred in the cotton braiding on the coils, and, of course, it was first attributed to impure varnish; but the analyses absolutely showed this not to be the case, and none of the analyses showed the presence of nitric acid in the new coils, whereas coils that had been at work showed nitric acid and nitrate of copper in considerable quantities, as well as sulphuric acid, doubtless formed in the way I have stated. The presence of moisture in what were properly dried coils is readily accounted for by the pumping action caused by the expansion and contraction of air as the machines were alternately cooled and heated, and this moisture would be increased by the presence of sulphuric acid formed as a secondary result of the brush discharge. I ought to say that I have seen exactly the same action in machines of other makes, and also in current transformers, and, somewhat to my surprise, on a copper rod passing through an insulator which was fixed rather near a damp wall.

On the lower coils, at a pressure between 2/4,000 volts, the amount of deposit was not enough to cause any trouble whatever, and the machines would doubtless have run for years at a pressure of 6,000 volts to earth, which is the pressure existing at the Bow Station.

Mr. Duddell's remarks on this matter are of extreme interest, and, as I have already said, I trust that he or others will carry out a more complete investigation on the point under proper laboratory conditions. I am happy to say that the machines which previously caused trouble have been partly rewound with solidly insulated coils, and the trouble has entirely ceased. I do not think it is good enough to trust to the complete removal of the moisture from the coils, even if this can be done. As a matter of fact, however, this is an exceedingly difficult thing to do, and many hours' drying in vacuo are required to eliminate approximately the whole of the moisture. As I have pointed out, even if this is done, after a very short time moisture will be found as new air is pumped through the coils.

Mr. Patchell.

Mr. PATCHELL (*in reply*): In the first place, Sir, I have to thank you for not giving any other gentleman an opportunity to ask any more questions! I think the most energetic speaker on the last occasion was Mr. Rider. I afterwards asked him if he would accept the

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Encyclopedia Britannica, with the Appendix, in full satisfaction of all claims, so that he might get out the answers himself, but he refused the offer! As he would not accept that, I am quite at a loss to know what to offer either Mr. Boot or Mr. Walker; but by the help of the report in our good friend, the *Electrician*, I have done my best to throw the various questions under the headings into which I have divided the paper, and I propose as far as possible to answer them in that order. The first we come to is, Why was the site not chosen far away, or somewhere else? The reason for that is that we were not exactly free agents. There was a special purchase clause in our Act which, in the event of the site being outside the City of London, compelled us to get the approval of the City of London authorities. We did not suggest to them that they should go down to Cambridge or the North Pole, although if it had been an overhead system that might have had its advantages, but we chose the best site that offered, out of a somewhat limited number, certainly, and one which pleased the authorities we had to please. Another reason was because in order to link the site by trunk mains to the area we had to supply, we required a special Act of Parliament, and, of course, the more local authorities whose areas are passed through the greater the trouble. In reply to Mr. Campbell Swinton's question, Why did we go abroad for our plant? I would answer him by asking another. May I ask our good friend why he goes abroad for his motor cars? He told me since the last meeting that he was very sorry not to have been here on that occasion, but he had to go out into the country, and unfortunately his motor car broke down, so that he could not get back in time! Fortunately we have had better luck, and I do not think we could have had a better plant had it been made in England. It is all very well for gentlemen to stand up in 1906, or at the end of 1905, and say, "You could have got that plant in England." I am sorry to have to deny it absolutely! When we had to buy the plant in 1900, not 1905, we asked for tenders in England, on the Continent, and in America. The best English tender was withdrawn at the last minute, due to Patent questions. We had a heavy load waiting for us, as we had not only our City business to pick up in the face of keen competition from our friends the City of London Company, who had been extremely stirred up by the granting of the Provisional Order for supply in their area to my company, but we also were depending on our new works for supplying our existing area, the demand in which has grown at a very satisfactory rate. It therefore was not a time to take unnecessary risks by ordering experimental machinery. That settled the first order, and, as is stated in the paper, the growth of the business was so rapid that the second order was placed before the first machinery ordered was delivered. Then, when we had a contractor who did his work and gave us absolutely satisfactory plant, we treated that contractor as an Englishman, and as we had always previously treated our English contractors—we gave him repeat orders. If contractors will give what is wanted at the best price, I believe in keeping with them. Although some people take the other view and have an engine-room very much

Mr. Patchell.

like a menagerie, I do not think that the possession of a varied collection is to the best interests of those who own the plant. My board took this view, and gave repeat orders to those who had served them well. As regards the question of pressure, I read Mr. Partridge's letter before reading the paper last month, and I repeat, to get it again on to the Proceedings, that I was in error in stating that the London Electric Company were stepping up everything at Deptford. I knew that they were stepping up, but I did not know that they were also partly generating at the high tension. The machines which I had seen when I was at Deptford were stepping up, and Mr. Partridge has told me since that that is quite correct; they were partly stepping up and partly generating at the full pressure. I made the statement in the paper, however, on a broader claim than that; I said we neither stepped up nor stepped down; we generated the current and, what was probably more important, we used the current at the full pressure. The Metropolitan Company are working at a higher pressure than we are, and, of course, have a high pressure to ground, as Mr. Highfield very ably pointed out; but that point I will refer to again later, as it comes up on another question. It is very valuable to get such a thorough-going tribute to the superiority of 3-phase over 2-phase from such an unbiassed gentleman as Mr. Highfield. It is not necessary for him to stand up for his own plant; he can run it down if he likes, for he is working a plant designed by other people, and he is now reaping the benefits, or otherwise, of his predecessors, so that he can look on 2-phase or 3-phase in an unbiassed way. As I selected 3-phase, you might naturally expect me to stand up for it! On the question of frequency, it has been asked why we did not take 25 cycles, one reason given in support of that figure being that we could then avail ourselves of the supply from some of the Power Companies which were promoted last year. These Power Companies were not promoted in 1900, nor even thought of! About the only benefit I believe accruing to the 25 cycles is on the line. There is very little benefit in the generating and very little in the motor generating plant, but the main benefit is on the line; and after weighing the whole thing up we came to the conclusion that 50 cycles was the best for us, that we could if necessary work motors or lamps, or anything else we wanted to work, by the interposition only of static transformers. At the present time certainly we are motor-generating everything to continuous current, but we are not tied to that. The matter was very thoroughly discussed in January, 1904, at the conference which was called to consider the question by the Engineering Standards Committee. The number of people then who stood out for 50 cycles only was astonishing, and they brought forward very good arguments. I think the alternative 25 cycles has been kept up mainly because so much plant of this type had already been made, owing to the fact that when that plant was designed there were very few people who could make rotaries, and most of these could only make them to run at 25 cycles, and I believe even at that their operation was somewhat uncertain. Since then, with a larger experience and an increased

knowledge, people have been able to design rotaries which will run at 50 cycles. It is now said that turbines will drive a 25-cycle machine which will drive a rotary, but of that I have not any experience; I only give it as it is stated. Professor Epstein and Mr. Mordey, both of whom have had considerable experience in the design of machinery, upheld the 50 cycles. As a matter of curiosity, I looked up the weight of static transformers given in two of the best known makers' lists and the result is rather interesting. A 150-kilowatt static transformer weighs, at 25 cycles, 6,000 lbs., and at 60 cycles, 4,950 lbs.; very considerably less for the higher frequency. A 300-kilowatt is 9,900 lbs. at 25 cycles, and 7,110 lbs. at 60 cycles. That gives an idea as to the cost of the static transformer for working at a lower frequency. Mr. Patchell.

With regard to the station buildings there is practically no criticism, with the exception that the crane is too low. It is not stated in the paper, but I mentioned the fact when I was showing the slides on the first evening, that at the time the building was designed we only had the drawings for the horizontal engine. I knew that vertical engines must come, and I intended to use them as soon as they came. The only vertical engine then available was the triple-expansion tandem-cylinder engine, which I objected to because of the difficulty of inspecting the cylinders quickly in case of need. I thought out what the size of the vertical engine was likely to be, and I designed the engine-room accordingly. The roof as originally designed was lower and the traveller was at the present level, but the architect suggested that the engine-room roof should be raised to the level of the boiler-room roof, and there was no reason to object to that. Of course, looking at the cross section now, it is quite easy to say that the traveller ought to be higher, as it would give more clearance over the engine.

Now we come to the portion of the paper which has been more criticised than any; in fact, sometimes one almost wondered, Was this the Institution of Electrical Engineers or the Institution of Mechanical Engineers? I refer to the section on boilers; and I am sorry that I have not made this part of the paper as clear as I hoped to have done. There has been great confusion among the speakers, particularly on the first two evenings, as to what was actually described as one boiler, and what was the large steam unit, or really what the size of the big boiler, as we generally call it, is. At the bottom of page 71 I state that we added a pair of boilers last year, and on the same page I also state that they were erected as one steam unit. I hoped that that would have been clear, but several speakers have rather missed my point there, and have thought that it was possible to steam one of those boilers without the other. That is impossible, as the combustion chamber is common. It would possibly have been clearer if, instead of putting the data of what can be bought as one boiler in the last column of Table III., I had doubled the figures. I am sorry for the confusion that I have inadvertently caused there. Then several gentlemen have said that I ought to have used mechanical stokers. I have been trying for several years past to use mechanical stokers, and have used a great variety, but the result has not been to show what some of

Mr. Patchell.

the speakers, who had got better results out of mechanical stoking than they had out of hand-firing, were able to testify. Either their firemen have been a good deal worse than ours, or their mechanical stokers have behaved a good deal better. Of course it is very easy to stand up and say, You ought to use a mechanical stoker. That opens a very wide field; but when a gentleman tells me that I should use one certain type of stoker, then we can come to close quarters and get on! One gentleman suggested that I should use the under-feed stoker. I have had two types of under-feed stokers, which were the only types then available, through my hands, but we could not get out of either of those stokers the work that we got out of the same boiler when hand-fired. We were obliged to abandon the experiments for the time being, but I hope in the spring, as soon as the load runs off, to resume them again, and I am still hoping to be able to use mechanical stokers. But I should not be satisfied with a mechanical stoker which would merely evaporate continuously at the normal rate. I will not use a mechanical stoker unless it will give the elasticity in the plant that we now get by hand-firing. I saw a very large station lately where the whole boiler-room had been equipped throughout originally with mechanical stokers, but the directors have found that was a fault. They could get normal loads carried quite comfortably, but they could not get any elasticity in the plant; and when the time came for increasing the plant they moved half the stokers from the old boiler-room into the new boiler-room, and they now have half of each boiler-room fitted with mechanical stokers and the other half hand-fired. I think you will find, generally speaking, that works which are equipped entirely with mechanical stokers are run in parallel with other works when running on a load which varies, not at the will of the man who owns the works, but at the will of the public over which he has no control. In Newcastle there are two stations, and one station can run to help the other. That is the same as running half a plant with mechanical stokers and the other half hand-fired. The same thing happens in Chicago and many other large towns, where one station can help another. Either that or working the stokers below their normal rate is the rule, so that when the pinch comes the stoker will respond to it. As regards making the back section of the boiler act as an economiser, I did not know that I ill-treated the boilers in so doing; as a fact it agrees with them; it may appear strange, but it does act as an economiser, and I will show in a moment why. When the boiler shown in Fig. 5 was first erected the back sections were nippled to the sections in front of them at the bottom as well as at the top. Experiments were made with the bottom nipples in and with them out, their place being taken merely by stays, and it was then found that by putting a suitable diaphragm in the back section and feeding the water in so that it could be sent down through half the tubes and up through the other half, it does not mix with the other water in the boiler, which is at the temperature due to the steam, until it gets nearer the fire. That enables us to work the back of the boiler at the lower temperature, which some of the speakers doubted, and it also enables the front of the boiler to

Mr. Patchell.

evaporate only, which, in the view of some of the speakers, is the only thing a boiler ought to do. Mr. Walker, who dealt so well with the matter, missed the fact that whether scale or granulated sediment is formed depends not only on the temperature but on the time which is allowed for it to form. If the temperature is raised slowly with the water comparatively quiet, scale will be formed, but if it is raised quickly and the water in rapid motion, there is not time for the crystals to adhere to each other and so form scale. I first realised this when experimenting many years ago with a Babcock boiler and an American apparatus which consisted of a feed pipe let into the top of the boiler instead of below the water line. The feed-water entered through a small nozzle over a cone, which was fitted with a blow-off pipe connected to pass out where the water formerly came in. That had the effect of spraying the water into the steam space; the whole of the solids in the water immediately crystallised like sand, fell into the cone, and could be blown out by the discharge pipe from the bottom of the cone into a tank. When they were dry it was possible to pour them out of one hand into the other like so many grains of sand. That showed that if the water is evaporated quickly and in motion instead of slowly, granulated crystals are formed instead of scale. That is what happens in the back of these boilers. We do not get scale on the tubes. The water is raised quickly to a high temperature, kept in motion all the time, and all that forms on the tubes is a little egg-shell scale, which clears off and falls straight to the bottom when the boiler cools down. Hence the value of the vertical tube; the granular deposit is dealt with by blowing off from time to time. The purifying action of the back feed-sections is astonishing, and would hardly be believed unless it had been demonstrated by actual results. Their tubes get coated with a thin scale as described, and the corners of their mud-drums hold the samples of granular deposit where the blow-off cocks will not disturb it; the sections nearer the fire are notably cleaner, and the sections between the main drum and the fire are practically as clean and free from scale after a year's working, and the tubes are as straight, as when they were new. They have all the appearance of having been worked with distilled water. There is, however, an entire absence of pitting or corrosion, either from the purity of the water or from air which might be entrained due to the water having been lifted by the air-lift system, as suggested by Mr. Walker. Doubtless the open heaters free the water from any air, which can escape there readily.

In response to the request for an analysis of the water, I have much pleasure in giving one, and also an analysis of the water from our Lambeth well and the water from a well at Watford. Several authorities have drawn attention to the fact that where water is drawn from strata heavily overlain with an impervious stratum it frequently contains large quantities of alkaline salts and more matter in solution than when the water is obtained from exposed rock. The quantities are expressed in grains per gallon.

Mr. Patchell.

	Sample of Water from Lambeth Well.	Sample of Water from Bow Well.	Sample of Water from Watford Well.
Calcium Carbonate	2·75	13·78	19·48
Calcium Sulphate...	None	None	0·89
Calcium Chloride...	None	None	0·17
Magnesium Carbonate ...	2·10	5·65	None
Sodium Carbonate	13·17	None	None
Sodium Sulphate	13·98	4·54	None
Sodium Chloride	14·66	5·48	1·67
Alumina, Oxide of Iron, &c.	Trace	Faint trace	None
Silica	0·56	0·64	None
Organic Matter	None	0·19	1·33
Total solids dissolved ...	47·22	30·28	23·55

It is interesting to note the difference between the Lambeth water, where the chalk is very heavily overlain with London Clay; the Bow water, where the chalk is nearer the outcrop, and the water from the Watford well, which is in exposed chalk. Both Lambeth and the Bow water, instead of boiling to a hard scale and practically keeping at the same density, boil to a soft scale or mud and are strongly alkaline. When I first began to handle such water I found it concentrated in the boilers to 1·20 specific gravity. We are not so tied up with regard to water-supply as one speaker seemed to think we were with our two wells. I wonder it did not occur to him that there is plenty of space for more wells in the eight acres where those two are bored. I do not suggest that eight acres can be studded with 15-inch holes, each yielding about 20,000 gallons an hour, but there is a good deal of water under that land which we have not at present touched. The question of changing the tubes on the boilers was mentioned. A reference to Fig. 5 shows that the firemen stand on chequer plates over the basement. Those chequer plates are made removable for the reason that when the time comes to change a tube it may be drawn out through a manhole at the bottom of the section into the basement. At present we have not had to change a tube, but we have plenty of head-room there should we have to do so. Mr. Venning put in some figures of the Stirling boiler as about to be used at Carville. Reference to his table shows that the only question between us is the normal evaporation, and that is just like talking about the nominal H.P. of an engine, which means practically anything! He has put in two columns the 33,000-lb. Hornsby boiler and the 33,000-lb. Stirling boiler, and rated the normal evaporation per square foot in the Hornsby at 3·04 lbs. per hour, while for the Stirling he has taken 5·17. If a fair comparison is made and the 5·17 is applied to the Hornsby, the result is 56,000 lbs. evaporation. The point to which we have at present worked it is not its limit, but only 4·6 lbs. per square foot of heating surface when we obtained the 100,000 lbs. per pair. In considering the Carville plant

rating you must not be misled. As we experienced last year, the gentleman who is concerned with Carville is very enthusiastic when giving nominal values to his plant. A 3,000-kilowatt turbine is 4,500 as soon as it gets up there, and a 10,000 turbine is 15,000 as soon as it comes under his notice; so that one would not expect his 33,000-lb. boiler to be what an ordinary engineer would call a 33,000-lb. boiler. Mr. Patchell.

Space is not everything, as was truly remarked by one speaker, and a large plant may be so crowded on to a small plot of land that the inconvenience in working it is immense. Double-decked boiler-houses are one solution, but not a happy one, and would surely never be built if all that is required could be arranged on one floor only. The Hornsby type of horizontal boiler can be built high, as there is no difficulty in supplying all the tubes with water, and the size described in the paper has, perhaps, the largest heating surface that can be arranged without having recourse to small tubes, as used in the marine-type boiler. It is, however, to be noted that marine boilers are now being built with only part of the tubes of small size, and the remainder 4 inch, so probably experience with small tubes has disclosed the disadvantage which might be expected to attend their use at such low angles.

As to the pump-room and feed arrangements, the question of water-heating has not been quite clearly followed out. We do not put the boiler pressure on the feed-heaters which are between the low-pressure cylinders and the jet condenser, because of the risk with those large vessels at boiler pressure in the engine-room in case of a joint blowing out. There would have been a very great risk of damaging the generators, and very little to gain from it. One gentleman was under the impression that we could get a higher temperature with a close-type heater than we could with an open-type heater. That I do not admit. If water is actually in the presence of the steam it will take the temperature of the steam. If a plate is put between them there is a drop in temperature in getting the heat through the plate, and when that plate is dirty with scale still more is lost, so that the dirtier the heaters get the greater the difference becomes between the temperature of the steam and the temperature of the water which is to be heated. The absence of stage heating was strongly criticised. I think, after the explanation about the boilers and the heating in the pump-room, it will be seen we are not altogether devoid of stage heating. We heat in the engine-room at the pressure simply of the tank on the top of the roof from which the water runs down by gravity, and with steam at the temperature due to the vacuum. We heat further by the tanks in the pump-room, which are open heaters, and into which all the steam pumps discharge. The next stage is at the backs of the boilers, which act as economisers; then at the front of the boilers, where the water is evaporated, and finally in the superheaters. At a test taken on the steam pumps at the maker's works in Newcastle, one came out at $43\frac{1}{3}$ lbs. and the other at $40\frac{1}{4}$ lbs. of steam per pump H.P. hour. I am not much concerned whether it is 35 lbs. or 55 lbs., because we get it back in the open heater, but, as the figures show, they are extremely efficient pumps. Of course, if we had only a 200-H.P. engine to consider, we

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might have repeated laboratory experiments with regard to stage heating and superheating, which are most interesting, but are not safe in a large plant with a variable load. Those who have argued from small experiments and then built large plants on those lines have sometimes burned their fingers. The question of condensing and cleaning the tubes I will not go into now, because I dealt with that point in the discussion in this room on Mr. R. W. Allen's paper before the Institution of Civil Engineers, which is reported in vol. 161, last year. I there described how, when I had been responsible for the working of surface condensers, I had cleaned them without drawing the tubes. I think Mr. Sayers, however, is quite right in stating that the concentration of the water and the trouble with the tubes is worse with cooling towers than when using fresh water every time. One gentleman asked whether there were any fans in the cooling towers. There are not; we only have chimneys, with natural draught.

We now come to the black spot in the paper. I refer to the question of the formation of nitric acid. Mr. Highfield first described it as a green spot, but I am sorry it became rather black, due to a letter which was sent all round to the press instead of being sent here, as it should have been, so that we might have had it out on the floor. I was asked to reply to that letter when it appeared in the papers, but I did not think it proper to do so until my turn came here. I now wish to tell you and the writer of it most unreservedly that I much regret having hurt his feelings in any way. There was not one idea of the kind that he attributes to me in my mind; I am still of the opinion that my criticism was absolutely justifiable, and I do not see that it reflects in any way upon either the persons who sold those machines or anybody who is in anyway connected with them. It is open to any of us to hold a different opinion to Mr. Highfield, and I certainly was not convinced by his experiments. Another speaker in the room to-night has also given his reasons for not quite agreeing with Mr. Highfield, but he did not quite interpret me correctly in saying that I did not think the trouble was due to nitric acid. I did not put it in that way. It is common knowledge that nitric acid is formed by what has been called the silent discharge. It has been tried commercially, but I believe the method was found to be too expensive. I first heard of the effect through friends who were experimenting with ozonisers. I am sorry that the letter I have referred to has absolutely garbled my statement. The words in which I have couched my opinion in the paper do, I maintain, most certainly not bear the interpretation that has been put upon them in the letter sent round to the press, and I object to the way they have been twisted. In fact, if the letter had been written this week, one would have said it was an electioneering document. Mr. Highfield stated his case very fairly and frankly, and it is far from my thoughts to gloat over him at all because he has had the trouble and we have not. I think the information that we have had from Mr. Duddell, and from the others who have touched on the point, has been very valuable, but I do not yet think that we know all about those Willesden machines. I believe Mr. Highfield was not

there at the time they were started—I am not sure; but we have not yet heard what type of insulation was used on them, or how much there was of it, how thick were the mica tubes, and how long clapsed after the machines were wound before they were put to work. Where were the machines in the meantime, and, when the machines were about to be put to work, how were they dried? Were they dried by putting fire-buckets about them, or were they dried from the inside by passing a current through them? If you refer to Mr. Highfield's original article,* you will find that some of the coils were damp. When I spoke of impurities, I was referring not only to dampness, which Mr. Highfield admits, but I had in my mind a further case. Twenty years ago a mechanical engineer was engaged in making lead secondary batteries. He was practically working from a recipe, like a cookery-book, but although special care was taken in the process, the results did not always come out the same. He wondered why. The materials were analysed, and returned as "commercially pure." The mechanical engineer was only works manager, and appealed to the technical chief of the company, and also to the board, and said, "May we not have a complete chemical analysis?" "No," they said, "the materials are commercially pure, they are quite good, and an analysis would cost at least five guineas." It is now common knowledge among secondary battery makers that absolutely microscopic quantities of arsenic, &c., are impurities, although they were then ignored in lead classed as commercially pure! I had no more in my mind when I wrote the criticism of Mr. Highfield's tests than I have just told you, and I am very sorry indeed that it caused any feeling. Mr. Patchell.

As regards trunk mains, we are told that we should have laid a lot of spare ways. Had we had our own way we should have done so, but, as is stated in the paper, we had no option; we were compelled either to lay mains on the solid system or armoured cables buried in the ground, and we elected to put in the solid system. We had no chance to put in either spare ways or boxes, and there is no void for the accumulation of gas between Bow and London on our mains. I quite agree with one speaker's statement, that the cost of pulling the ground up again to relay further mains is under-estimated in some quarters. Last year we had figures put before us seriously as the cost of laying mains, which would not in some cases pay for the reinstatement of the roadway. The joint mentioned as better than Fig. 14 is the B.I.W. joint, which is wrapped with linen tape. I have lately heard of even a better joint than that, namely, micanite tubes. Instead of the joints being made as we made them, or when a tape is wound round the cores in the joint hole, a micanite tube is made, and boiled in the factory so that there can be no dirt in the micanite, reboiled by the jointers, and then slipped on over each core. If a man is working in a hole in the road he is apt to get his tape damp or dirty, no matter how good a man he may be. The porcelain insulators have given us no trouble whatsoever. The only troubles we have had are the troubles mentioned in the paper. The

* *Electrician*, vol. 54, p. 572.

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cable-charging gear has been found fault with. From what we have heard from Mr. Duddell to-night, one hopes that, with regard to the cable-charging gear, we will not have to use it now because we have oil switches. Mr. Duddell's experiments are extremely interesting, and they go to support what I have been told elsewhere, that the oil-switch will enable a cable to be taken off or put on at full pressure. The remark made with regard to this gear, however, that we had to run up through a range of frequencies, is incorrect. We can get full frequency with 4,000 volts, at which we put the cable on, and then increase the volts with the normal frequency. The curves of the experiments which Mr. Duddell showed us go against previous opinions to a small extent. It has generally been believed that it helped matters if, before switching on a long cable, a transformer or an induction motor, or some other self-induction, were put on at the far end of it, but in his case, as we saw, the transformer did not help matters materially. Mr. Highfield also appears to have had a good experience with his switching off. Unrehearsed effects are sometimes useful, though at other times they are apt to be startling, but at any rate they are instructive. One speaker on the motor generator question asked why did I prefer synchronous machines; he had found induction machines were better. I think that gentleman is working at 6,000 volts, and I am working at 10,000. If he had been working them at 10,000 volts some years ago I think he might have changed his opinion.

With regard to the working results, I have been asked for many things. The first speaker asked for the cost of the coal. It is about 13s. a ton delivered. Then I was asked for the load factor and the coal consumption. It would not do to tell everything at the start, otherwise you would not come to hear the reply to the discussion, but I have not the least objection to giving you the figures for each year since we started, with the B.T.U. delivered into trunks, the pounds of coal per B.T.U., and the load factor, and I am quite prepared to put those figures alongside any others, as I fully believe they will justify my claim that the plant is highly efficient. When we are considering this way of appreciating a station, we must be quite sure whether we are talking about B.T.U. generated or B.T.U. delivered into the mains. Some people use the terms as synonymous, but according to the arrangement of the station there may be a very great difference between the two quantities. In 1902 we only worked seven months; our load factor was 7·85 per cent., and the pounds of coal per unit 4·17. That, as I mentioned the other night, was large Welsh. In 1903 we got a full year's work; the load factor was then 10·66, and the pounds of coal per unit into trunks 3·46—that was large coal. In 1904 the load factor was 13·07, and the pounds of coal per unit delivered into trunks 3·43, when using partly large and partly small. In 1905 we used small coal almost entirely. The load factor is a little better, 13·69, and the coal very slightly worse, 3·64 lbs. with small instead of 3·43 lbs. with large. If that is put into pence, the difference is very marked. Mr. Sparks mentioned his results. Last year he was good enough to give them in evidence when we met for so many days not

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far from here. I have looked up to see what he gave us then, and I find they are not quite the same figures that he gave us the other night. City Road is not a high-tension station; the bulk of it, I believe, is 480-volt work, which goes to supply motors in the Clerkenwell district. For the six months ending 28th of March, 1905, Mr. Sparks' coal cost 11s. 8d. per ton, and 0·295d. per B.T.U. delivered into mains, which is equal to 4·72 lbs. per B.T.U.; and he stated that on City Road station he had a 26·4 per cent. load factor. In the published accounts for all his works in 1904, the B.T.U. generated are rather over ten millions. We do not know exactly what the price of the coal was then, but if it was the same, 11s. 8d., he took 5·6 lbs. of coal per B.T.U. generated. Probably the coal was rather dearer in the early part of 1904 than later; if so, of course that would make the pounds of coal per B.T.U. rather less. If we turn those figures into their cash equivalent, we find that in 1904 his costs were 0·35d. per B.T.U. generated for coal, and I find from his evidence in another place that the cost of coal per B.T.U. delivered to mains, which is my standard, was 0·373d. on a 17·86 per cent. load factor for all his stations. Ours for 1905 was 0·26d. on a 13·69 per cent. load factor. Then we have one of the much-advertised turbine stations, Neepsend, whose figures for the year were published by the *Electrician* on the 8th of December last. The B.T.U. delivered into trunks were just under 3¼ millions, and the load factor 13·4 per cent. The lbs. of coal per B.T.U. delivered into the trunks were 4·04. I will take that a little further. Earlier in the year that station was stated to be using Shire-Oak slack. I have tested that slack, and found it to have 13,000 British thermal units calorific value. Applying that figure to the year's working, we get an efficiency of 52¼ thermal units per watt-hour, with a turbine station. We have at Bow for 1904 obtained 51·45, and for 1905, 50·96 thermal units per watt-hour. Similar figures for English stations are not available, but I will endeavour to obtain them; I have them for some of the large German stations, and I hope to be able to put them all in a table at the end of the discussion. The best of them is Berlin, which, as you know, has one of the biggest plants in the world, and one of the heaviest loads. Their coal per unit generated—I do not know really whether it is delivered into mains, but these German figures are all got out in the one way—is 3·1 lbs., and the British thermal units per watt-hour 38·46. That is the best performance I have been able to find; they have an enormous load and a very large load factor. I will not detain you by reading them now, but I have the figures for Hamburg, Dresden, and Frankfort, where there is one of the turbine plants which have been so much advertised. The figures go to show that it is not a bad way of comparing the value of a station, and I certainly would prefer to take a twelve months' performance on that basis than a ten-hour test.

As regards the losses in the system or the number of men employed in all the departments, I am sorry I cannot give them right through. The loss on one trunk main on a 1,000-kilowatt load is 3 per cent. We took a Hopkinson test of one of the motor generator sets with

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specially calibrated instruments, but with the ordinary gear that we are working with every day. This was an extremely ticklish thing to do, because we found that varying one stop on the shunt resistances, or altering the brushes very slightly, varied the load considerably, the balance was so delicate between the two pairs of machines. When you have got the figures you do not quite know what to do with them, and the fairest way seems to be to halve the total losses between the two machines. When taking the Hopkinson test on a motor generator, the test includes two motors and two generators; to get the full load on the generator set the motor is overloaded, but if we halved the losses between the two sets, in one test we got 86 per cent., and in another test on rather a higher load 87 per cent. efficiency.

At last we come to the appendix and the question of surges, which Mr. Duddell has thrown further light upon to-night. I hoped that several speakers would have dealt with those points, because I believe them to be of the utmost importance to the profession, and unfortunately very few who have any information on the subject have published it. I hope that others will yet contribute to the written discussion their experience on those questions. The figures that Mr. Duddell has put before us to-night are most interesting, and will be fresh in your minds. I do not wish to criticise them in any way, but simply to thank most heartily Mr. Sparks for granting the permission, and Mr. Duddell for bringing them forward with his lucid remarks.

The experience of Mr. Wüthrich with extra high-tension machines is interesting, and it would appear that he refers to what may be recognised as two distinct sources of trouble. Unless special precautions are taken the switching of E.H.T. coils on to machines causes trouble in the coils nearest the switch, quite apart from any silent discharge or nitric acid effects. The trouble is due to the first few coils taking the shock of the sudden rise in pressure, and is almost analogous to the shattering of the head of a pile when a weight falls on it, so must be adequately provided against. The curve suggested as the standard will be of little value unless the machines and coils whose leakages are to be compared with it are tested at a uniform standard degree of dryness, which in the case of large machines is a condition very difficult, if not impossible, to attain.

Since the paper was read great prominence has been given to the commercial production of nitric acid electrically in the technical press, and particularly in Dr. Silvanus P. Thompson's Royal Institution Lecture, where the Birkeland-Eyde and other processes are described.

The cables which failed had all been pressure-tested in the factory, and only failed to stand the pressure test after they were laid. They had not been put to work. Probably the fact that they were laid during a frosty winter aggravated the trouble.

The tests referred to by Mr. Pooley would appear to have been factory tests, and not tests made upon long lengths of cable after they were laid, unless he was exceptionally fortunate in getting power enough at 70,000 to 80,000 volts to test the cables before the plant was started, and also had joints which would stand such pressures.

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TABLE A.

Works, 1905.	Output in Units delivered to Mains.	Lbs. Coal per Unit.	Cal. Value in B.Th.U. per lb.	B.Th.U. per Watt-Hour.	Load Factor per cent.
Newcastle-on-Tyne (Carville for 6 months ending June, 1905)	14,604,800	3·13	11,000	34·43	37·0
Boston (Mass.) Edison ...	49,878,584	2·66	14,715	39·13	28·2
Chicago Edison (Fisk St.) ...	130,175,800	4·50	10,100	45·45	33·0
Glasgow Corporation	20,558,500	4·50	10,500	47·25	17·4
Manchester (Stuart St.) ...	28,189,455	3·57	13,500	48·20	30·3
Powell-Duffryn Steam Coal Co.	4,500,000	3·75	13,000	48·75	37·0
City and S. London Ry. ...	6,644,331	4·41	11,500	50·72	35·0
Charing Cross Co. (Bow, 1905)	12,174,104	3·64	14,000	50·96	13·7
" " " (Bow, 1904)	10,340,657	3·43	15,000	51·45	13·1
Sheffield (Neepsend)	3,499,428	4·04	13,000	52·52	13·4
Metropolitan E. S. Co. ...	22,711,000	4·64	11,800	54·75	22·0
Central Co.	7,102,960	4·20	14,000	58·80	12·5
County of London Co.... ...	11,350,000	5·50	11,000	60·50	18·9
Salford	10,666,001	4·37	14,320	62·58	28·0
Leeds	8,436,817	7·15	11,000	78·65	14·5
St. James and Pall Mall Co. ...	6,654,217	5·54	14,200	78·67	18·0
Berlin, 1905...	141,059,129	2·38	12,368	29·44	30·40
London Electric Co.	14,235,423	4·60	12,000	55·20	25·0
Bradford (generated)	14,723,356	4·12	13,000	53·56	28·0
Westminster Co. (generated) ...	11,610,914	4·96	14,394	71·39	27·0

TABLE B.

Works.	Units Generated.	Lbs. Coal per Unit.	Cal. Value in B.Th.U. per. lb.	B.Th.U. per Watt-Hour.	Load Factor per cent.
Vienna, 1904	45,939,840	2·7	11,938	32·23	35·2
Elberfeld, 1904	7,206,950	3·0	12,420	37·26	27·2
Berlin, 1904	113,389,947	3·1	12,576	38·98	31·1
Buenos Aires, 1904	32,722,381	3·0	13,500	40·50	—
Hamburg (Zollverein), 1904 ...	12,914,177	3·0	13,500	40·50	38·6
Frankfort a/M., 1904 ...	16,431,832	3·3	13,500	44·55	29·9
	2,121,080	3·7	13,500	49·95	20·9
Hamburg (combined), 1904 ...	27,188,640	3·4	13,500	45·90	28·4
Coln a/Rh., 1904	13,126,850	3·0	12,870	40·33	37·8
Munich, 1904	12,888,991	3·7	12,705	47·23	24·2
Copenhagen, 1904	13,280,515	3·9	12,519	48·82	29·3
Charlottenburg, 1904	6,747,000	4·5	11,340	51·03	24·0
Oberschlesischer Industrie-bezirk, 1904	27,286,995	4·8	10,800	51·84	35·2
Dresden, 1904 { Power	12,528,657	6·5	8,244	53·58	30·8
Dresden, 1904 { Light	5,464,405	7·2	7,560	54·43	22·9

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The additional notes communicated by Mr. Highfield are valuable as filling up blanks in the history of the Willesden machines, and everyone will concur with him in hoping that a complete investigation of the whole subject may yet be made by some competent person.

The publication of the data in Table A has been only possible by the courtesy of the engineers in charge of the various plants, to whom I hereby tender my hearty thanks. The 1904 figures in Table B are calculated from the Tables of Statistics issued by the Vereinigung der Elektricitätswerke. The figures quoted in my reply are from an earlier volume, while those in the table are the last published.

I thank you all, gentlemen, for the way in which you have not only taken part in the discussion, but for having so patiently listened to the reply.

The President.

The PRESIDENT: Gentlemen, Mr. Patchell has favoured us with a most valuable paper—not only valuable for the information it contains, but on account of the thoroughly practical and animated discussion which it has given rise to. I am sure you will all unanimously join in passing him a very hearty vote of thanks for the paper which he has been good enough to read.

The vote of thanks was carried by acclamation.

Proceedings of the Four Hundred and Thirty-second Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, December 14, 1905—Mr. John Gavey, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on December 7, 1905, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following transfer was published as having been approved by the Council:—

TRANSFER.

From the Class of Associates to that of Associate Members.

James Percy Winn.

Messrs. W. H. Molesworth and J. O. Girdlestone were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected:—

ELECTIONS.

Associate Members.

Courtenay Harold W. Edmonds.
Walter Leonard Lorkin.
Howard Marryat.
Harman Visger.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Day, Davies & Hunt, Éclairage Électrique, A. Ferran, The High Commissioner for Canada, E. Raymond-Barker, G. Semenza, S. P. Thompson, Whittaker & Co.; and to the *Benevolent Fund* from Mr. C. F. Wilkins, to whom the thanks of the meeting were duly accorded.

The discussion on Mr. W. H. Patchell's paper was continued. (See page 110.)

The meeting adjourned at 9.30 p.m.

Proceedings of the Four Hundred and Thirty-third Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, January 11, 1906—Mr. JOHN GAVEY, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on December 14, 1905, were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the Class of Associate Members to that of Members.

Frank Anslow.
Geo. A. Bruce.
Arthur W. Manton.
Hugh B. Maxwell.
H. L. T. Wolff.

From the Class of Associates to that of Members.

William J. Larke.

From the Class of Associates to that of Associate Members.

Wilfrid L. Browne.
Harry Curphey.
Henry Joseph.
F. O. J. Roose.
Harold Walker.
Arthur H. Wilson.

From the Class of Students to that of Associate Members.

Alfred H. Bennett.
William Bradshaw.
Herbert H. Clare.
Clement L. Faunthorpe.
Robert B. Forster.
Chas. B. Franklin.
Francis H. Goodall.
Richard P. Jephson.
Albert L. Stanton.
Clive B. Tutt.
Guy L'Estrange Walsh.
Humphrey G. Wightwick.

Messrs. B. B. Heaviside and H. Brazil were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Clifford Alfred Bowen.
Douglas James Callow.
Henry Burden Harris.
William H. Heaton.
Arthur Mountain Kidd.
Harry Lamb.
Andrew Forrest Miller.
Hopkin Morgan.
Felix I. A. Owen.
John Lewis Packer.
George Wordsworth Peard.
Fritz Hubert Preedy.
Edward John Skinner.
James Walter Spark.
Ernest Sykes.
William Thomas E. Wallace.

As Associate.

Hermann Oppenheimer.

As Students.

John Brodie.
Harry Alburn Caldwell.
Herbert Reginald Denson.
Stuart Arundell Martyn.
Robert Shaw Miller.
Verner Carl Peycke.
Robert Rankin.
George B. Reveley.

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. I. Braby, A. Burton, Major P. Cardew, F. W. Clements, Col. R. E. Crompton, R. A. Dawbarn, L. Drugman, W. Duddell, A. H. Finlay, R. Hammond, R. Hardy, H. E. Harrison, A. Hay, E. Hutchinson, Captain H. B. Jackson, R.N., W. N. Y. King, H. W. Miller, C. W. G. Nelson, S. R. Roget, J. H. Rosenthal, M. Solomon, Sir J. W. Swan, H. D. Symons, H. W. Young; and to the *Benevolent Fund* from Messrs. I. Braby, W. C. Clinton, A. Denny, B. M. Drake, W. Duddell, E. Garcke, F. Gill, R. Hammond, J. S. Highfield, S. H. Holden, Sir H. C. Mance, C. H. Merz, C. C. Paterson, H. L. Riseley, Sir D. Salomons, Bart., A. A. C. Swinton, F. J. Thompson, T. C. T. Walrond, Capt. R. F. Willis, J. Woodside, C. H. Wordingham, to whom the thanks of the meeting were duly accorded.

The discussion on Mr. W. H. Patchell's paper was concluded. (See page 129.)

The meeting adjourned at 9.50 p.m.

DUBLIN LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

PERCY S. SHEARDOWN, Member.

(*ABSTRACT.*)

November 9, 1905.

After some consideration as to what should be the subject matter of the address I am to have the honour of delivering to you this evening, it occurred to me that it might be profitable to try and incorporate in it some information given, and opinions arrived at, by the authors of some papers presented at the recent International Congress at St. Louis.

High-tension Transformers.—Attention was drawn to the great development in high-tension three-phase transmission in America during the last few years, practically all by polyphase current, present statistics showing that the apparatus manufactured by the leading American companies for generation at 10,000 volts or higher provides for the transmission of 1½ million H.P., whereas ten years ago there was but one single case of transmission of 200 k.w. at 10,000 volts, this by single phase.

American-made transformers for high-tension transmission may be divided into two general classes—oil insulated and air blast; the oil-insulated transformer being again divided into two classes—self cooling and artificial cooling. The self-cooling oil transformer requires no attention, but the capacity is limited to about 500 k.w. For artificial cooling practically the only method now employed is forcing or syphoning water through coils of brass or copper tubes placed inside the transformer case below the surface of the oil. The air-blast transformer is not used for pressures which exceed 20,000 volts, the power required for cooling being usually from one-tenth to one-quarter of 1 per cent. of the transformer capacity with a pressure usually less than one ounce per square inch.

American experience seems to indicate that fire risks with oil-insulated transformers are very considerable, but it was generally conceded that fires that had occurred in transformers had generally originated outside the transformer, and were not due to failure of the transformer coils themselves, it being strongly advocated that oil

transformers should be placed in fire-proof apartments by themselves, and completely isolated from the rest of the station, so as to remove them as far as possible from the danger of being ignited from outside sources. It was also pointed out that with naturally cooled oil transformers there was no advantage in ribbing the inside of the cases, as practically the whole of the heat potential drop is between the outside surface of the iron and the air in contact with it.

A good deal of time at the convention was spent with papers dealing with extra high-tension long-distance transmission. One of the most interesting papers was by Professor F. G. Baum, who has under successful operation in the district of the Sierra Nevada mountains of California a transmission scheme which had apparently been operating without experiencing the troubles found on many other similar lines in other parts of the country. The paper stated that the system described had continuously in operation about 700 miles of line at 50,000 volts, 70 miles at 40,000 volts, and a great many miles at 23,000, 16,000, 10,000 and 5,000 volts, and mentioned that in a short time some of these lines would be operating at 60,000 volts. Professor Baum's practice was to generate at 2,300 volts and then step up. They had practically no trouble with their transformers, even where the pressure was raised as high as 80,000 volts. With regard to switchgear, they found that the oil-break switch was the only one that would stand heavy duty at the high pressures dealt with, and that this type is less likely to produce violent surging on opening a circuit than has been experienced with the flare type of air-break switch. Professor Baum considers that the weak point of the transmission system is the insulator, and that with an insulator to stand 100,000 volts, in his opinion this pressure is possible.

Storage Batteries.—With regard to storage batteries, the opinion of American station engineers has completely changed within the past few years, statistics showing that in 1894 only two large stations had batteries, the total capacity being 938 kilowatt-hours. In 1904, 22 generating stations, 68 substations, and 8 exciter batteries had been installed, with a total capacity of 124,242 kilowatt-hours. As 95 per cent. of these storage batteries have been installed by one firm of makers, there is naturally not much difference in design. The reversible booster which is in English practice now nearly always installed instead of regulating cells, is practically unknown in the States, and strong comment was made on this by English engineers in the discussions on storage batteries. Its non-introduction into America is probably due to the fact, as stated, that the battery trade is practically in the hands of one firm ; the ostensible reason put forward by American engineers is that they place so much faith in their storage batteries, in case of temporary failure of their other plant, that they do not like jeopardising this safety by adding to it a piece of rotating machinery.

Wooden diaphragms are now often inserted between the plates as separators in place of the glass tubes hitherto generally used. Not only is this type of separator effective in preventing any possibility of short circuits forming between the plates, but it is claimed that the

capacity of the batteries has been very much increased since these wooden diaphragms were installed. The diaphragms affect only the negative plates, it having been proved that, after a short time in use, negative plates often gave only 80 per cent of their guaranteed capacity. On the other hand, where the wooden diaphragms had been inserted in place of the glass separators, in three weeks' time they could get from 110 to 115 per cent. rated output, so that the life of the negative plates was increased by at least two years.

With reference to the electric lighting of large cities, the almost universal system is to generate at the power-stations three-phase alternating current at pressures of about 6,600 volts, and transmit at this pressure to substations placed fairly close together, which feed direct into the low-pressure direct-current network usually through rotary converters, although motor generator sets are sometimes to be found. The low-pressure direct-current system is usually three wire, with from 210 to 220 volts across the outers. The lamp known in America as the double-voltage lamp had made no headway there, as it was claimed that the greater efficiency of the low-voltage lamp more than compensates for the interest on the additional copper required; but it should be noted that in America it is usual to include the supply of lamps and renewals in the charges made for electricity, and it is also stated that in a 220-volt pressure network fed by high-tension rotary converter substations the copper required in the network is no greater than in a 440-volt system when fed direct from one generating station, as in the former case it simply means dividing up the substation machinery into more substations, so as to feed at more numerous points into the network.

The American standard lamp is 16 C.P., operating under a strict guarantee at 3·1 watts per candle.

Steam Turbines.—Some important papers on steam turbines were discussed, and although it was admitted that up to the present the best steam efficiency shown by turbines had not exceeded the best steam efficiencies recorded with reciprocating engines, the very important fact was emphasised that whereas the best steam efficiency of the reciprocating engines is confined to practically one load, the efficiency dropping off very rapidly on each side of this most economical load, with the turbines the efficiency curve was comparatively speaking flat. The efficiency given for a 750-k.w. turbine at normal full load was 11·79 lbs. of steam per B.H.P.H.; at 24 per cent. overload, 11·42 lbs. of steam per B.H.P.H.; and 41 per cent. overload, 11·5 lbs. of steam per B.H.P.H. A great future was predicted for steam turbines as auxiliaries to existing plants, due to the fact that the steam turbine works most efficiently with a steam pressure lower than that with which the reciprocating engine can deal. Attention was also drawn to the great increase in efficiency which could be obtained with existing steam plant by arranging the engines to exhaust into a low-pressure turbine, driving a generator working in parallel with the plant driven by the reciprocating engines, and then allowing the turbine to exhaust into a high vacuum. It is claimed that

the output at many large existing stations could be increased as much as 30 per cent. without any increase in the fuel consumption or alterations in the boiler plant.

In connection with the steam turbine another considerable economy might be obtained by the utilisation of waste heat from gas-engine installations. The best gas engines turn about 20 per cent. of the heat of the fuel into useful work; the remainder is lost either in the exhaust gases or in the heating of the water to jacket the cylinder and other parts. Mr. Emmett points out that it should be possible to pass the exhaust gases through tubes to low-pressure boilers fed by hot water which had passed through the jackets of the engines. These boilers could then deliver steam to simple low-pressure turbines with suitable condensers.

GLASGOW LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

JOHN M. M. MUNRO, F.R.S.E., Member.

(*ABSTRACT.*)

November 14, 1905.

In thanking the members for the honour conferred on me by electing me as Chairman of this Section, it occurs to me that perhaps the choice of a chairman has been somewhat influenced by a desire to recognise the early work of the pioneers of the Electrical Engineering Industry in Scotland. My thoughts first turned, therefore, naturally, towards these early days as providing a subject for an address. But instead of recording my own personal experiences, it seems to me that the city in which we meet suggests a subject. Glasgow has a world-wide reputation for corporate enterprise, and I will speak therefore of the development of electricity in Civic Service.

The Corporation Gas Bill of 1882 proposed to take powers to supply electric light in Glasgow, but the clauses were deleted before going to Parliament. The Miller Street station of Messrs. Muir, Mavor & Coulson was opened in 1884. Messrs. Anderson & Munro's undertaking—the Kelvinside Electricity Company, Limited—was incorporated in 1889. The first Corporation supply station, Waterloo Street, was opened early in 1893.

The first electric traction line was opened in October, 1898, and the whole Glasgow tramway system was electrically driven by 1901–2. There are now fully 700 cars, and over 150 miles of track. The total capital expenditure equals about £2 15s. per inhabitant of Glasgow, and every man, woman, and child takes about 200 journeys a year at a cost of about 15s. each. (The population of greater Glasgow is 1,000,000.) Notwithstanding the triumphs of electric tramway traction, many of its problems still remain for solution. It is still impossible in Glasgow to recover much of the energy spent in stopping for helping to start a car. Mechanical appliances have been devised for this, but good electrical ones are now on the market. The problem of an elastic service adapting itself fully to the varied demand of the time of day and year is yet unsolved. Congestion of traffic will compel the city to add overhead or underground routes.

The energy generated at the various generating stations has increased from about 408,000 units in 1893 to over 44,000,000 units in 1905.

The following figures refer to the year 1904-5. Gas figures are added mainly because they affect the question of coal, and may yet be otherwise closely related to the subject in hand. By useful units, I mean the kilowatt hours sold by the electricity department, or issued from tramway substations for traction purposes and lighting of cars :—

	Units Generated.	Useful Units.	Operative and Incidental Losses.	Kilos Maximum Load.	Tons of Coal.
E = Electrical department =	20,340,556	...	...	...	47,356
E bought from T... ... =	1,243,532				
	21,584,088	18,248,468	15½%	13,437	
T = Tramway department =	23,918,863	...	...	8,517	35,267
T sold to E ... ... =	1,243,532			or	
	22,675,331	17,951,961	20½%	6,300	
Combined totals	44 259,419	36,200,429	...	19 737	82,623
Cubic feet of gas generated...	6,449 539,000	...	...	...	680,235
Total tons of coal... ...	...	...	...	...	762,858

The load factors, stated as percentage, work out at, for tramways, 41 per cent. excluding current sold to E, or, including this, at 30·8 per cent., and for the electricity department on total amount generated, including current bought, = 18·3 per cent. Coal per useful unit (plus and minus amount sold by T to E) comes out at, for tramway department, 4·1 lbs. coal per useful unit, and for electricity department, 6·2 lbs.—a coal difference doubtless due to such factors as larger plant units, smaller stand-by losses, more regular hours of load, and, in smaller degree, to other points of difference of load factor. For, of course, the chief effects of load factor come in in the standing charges.

I made out the probable corresponding figures for coal for the year 1915. As no two men would quite agree on the effect of the various factors which may and must influence a prolongation into the future of the curves of rate of past increase, I do not give details of the resulting figures. Improvements in generating methods and in the efficient use of the energy, tend in themselves to lower the total consumption. Increase of population, of trade, of money, and of new applications of electrical energy, tend towards increase. The figures seemed to suggest, however, a total coal consumption, in 1915, for electrical purposes, of some 200,000

tons, and for gas, of 560,000 tons—a figure which might be much increased if a very cheap gas were greatly used for heating purposes. Much of the gas coal is necessarily derived from special sources, but it may be of interest to state that the annual output of coal of the Lanarkshire coalfields is 17,000,000 tons. It has been estimated by some that this rate of output could be continued for a hundred years or thereby.

These figures raise several questions of policy primarily applicable to large cities.

a. Ought the production of electrical energy to be combined under one management distinct from the great departments which have to do with its sale, general distribution, and use for traction, light, power, etc. ?

b. Ought these great coal-burning undertakings to have their works outside the city proper ?

c. Ought a great city to do with coal as most have done with water—that other great necessity of life—acquire their own coalfields as they have acquired their mountain lochs and water-gathering areas ?

If transmission of producer gas at high pressure were found to be as economical as electrical transmission of power, we may yet have the gas department responsible for the supply of fuel to the power station when gas engines are used.

[Figures relating to the efficiency of gas transmission were quoted, and suggestions made regarding the generating of gas under high pressure, and its delivery at high pressure to gas engines.]

As to the use of water-power, the city water supply can yield only 18 theoretical horse-power per foot of effective head. The reservoirs give only the head required for other purposes; while the great conduits from the Highland lochs were "in train," and could afford no external power.

With regard to the utilisation of power from refuse destructors, while it might be wise to use their heat for the generation of electrical energy in small towns, the site and arrangements of the power stations of a great city could only be affected disadvantageously by modification to the requirements of refuse destruction. Yet the refuse of Glasgow might be capable of yielding 5,000 B.H.P. for 18 hours a day for six days per week. And destructor steam production is most economical when it forms part of a much greater steam generating plant.

The spread of car lines outside the city is pregnant with suggestions of coming change. If city cars run to Paisley and Johnstone, why not to Edinburgh and Kilmarnock ?

If the Imperial Government found it necessary to take over all civic telephony because towns needed interconnection, and country districts desired telephonic facilities, how much more, on the like principles, will they desire to take control of traction in and between towns ? Will the electrification of main line railways, too, thus be after all a Government undertaking ?

Again, if the great District Electricity Supply Companies prosper as they hope, will not the time come when their power over trade in general may be too great, and the disadvantages of competing systems too glaring, so that agitation will arise for their absorption by Local, if not by Imperial, Government?

In conclusion I may perhaps be permitted to make some suggestions regarding the policy of the Institution in respect of Local Sections.

By the familiar words "The Parent Institution" we recognise—and with pride—the filial relationship of this Local Section to the distinguished body of which we form a part. We are all members first of the Institution of Electrical Engineers, and secondarily of the Local Section. Now when any body begins a process of self-subdivision, there are two dangers to fear. One is that the parts may become wholly separate and distinct, with risk of unfriendly rivalry; the other is that subdivision may go on indefinitely until the sections become small, weak, and insignificant. Few will fear the former risk; the avoidance of the latter will be the result of a wise policy. For such a policy we may fully trust the General Council of the Institution.

The Glasgow Section may almost be described as the Scottish Section. But the narrower name has been chosen meantime so as to keep open the question of further subdivision. The number of men eligible for Membership, or Associate Membership, of this Institution will vastly increase. Not only so, but just as every electrical ought to be also a mechanical engineer, every mechanical will soon have to be also an electrical engineer and interested in electrical affairs. A section formed in Edinburgh would be soon followed by one in Dundee, Aberdeen, and Inverness, and these by Perth, Galashiels, and these by others, until every town and even village had its section meeting locally for discussion.

It appears to me, however, that subdivision on the lines indicated would so reduce the influence and importance of Local Sections as to impair the efficiency of the Institution as a whole. Even the task of selecting a few papers for publication would become burdensome. The best papers would be reserved for London. Most of them would be unprepared or left unread. It would not be worth while for a capable and busy man to prepare a paper for a little section, knowing that probably the paper would be crowded out of publication. In the end only the minor men would trouble to attend local meetings.

The supreme government of all the sections, and subsections, if any, would vest in the President and General Council as now. These would decide also the number and place of general or united meetings, if any. I suggest two annually—one in London and one in a provincial centre in turn. To such a small number of united meetings one might hope many members could go.

It appears to me that such a policy would add to the dignity and influence of the present local sections, attract the best local men to their meetings, and give their members something real to labour for and uphold.

The frequent and healthy desire for very local meetings could be

met by the formation of subsections under the control of the section in whose area the meetings were held. The organisation of such subsections would be of the simplest, and papers read and discussed thereat for the interest and mutual improvement of those attending would not be deemed to be read before the Institution.

Gentlemen, I end as I began, by invoking your assistance to uphold the usefulness and promote the efficiency of this Local Section of the Institution of Electrical Engineers.

LEEDS LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

A. B. MOUNTAIN, Member.

(*ABSTRACT.*)

October 25, 1905.

I have thought that it may be of interest to you if I refer briefly to the development of electricity supply undertakings during the last ten years, with some conclusions which, I think, may be drawn from the approximate figures I shall place before you.

At the end of 1894 there were 60 undertakings, with a capital expenditure of £6,107,680; at the end of 1904 there were 445 undertakings, with a capital expended of £61,961,313.

The consuming devices reduced to the equivalent of lamps connected in 1894 numbered 2,031,398; and at the end of 1904, 19,971,435.

The units sold in 1894 numbered 30,203,766, and in 1904, 448,078,057.

The average price obtained per unit sold in 1894 was, by Companies 6·08 pence, and by Municipalities 5·32 pence; in 1904 the average price obtained by Companies was 3·9, and by Municipalities 2·7.

These figures are an indication of the progress made in ten years, the capital expended and lamps connected having each increased proportionately by ten times, and the units sold by nearly fifteen times, while the price obtained has decreased by 48 per cent.; but interesting as these figures may be as a summary of the result of ten years, they are much more interesting if we try to appreciate the condition of things at either end of the period under consideration.

In 1894, the difficulties surrounding the erection of an electricity works and the selection of the best system of supply were very considerable. The uncertainty that such works would prove financially successful or were likely to grow to the extent they have done forced engineers to plan the works upon much too small a scale, but even if the desire to erect larger generating plant had been there, it was practically impossible to obtain reliable and economical plants of large size. In addition to these difficulties, the selection of the system of supply was very much a choice between two evils: if an alternating current

system of supply was adopted, motive power developments were a matter of hope only; whereas if direct current was selected, owing to the low pressure then generally in use, the cost of distribution over large areas was prohibitive.

The result was that most of the works constructed at this time were planned upon a small scale, with small generating plants in some cases placed in most unsuitable positions; the mistakes, if such they were, have in most cases been recognised, and extension has been made upon sound lines, with generating plant of much greater capacity; still, the original errors have added largely to the capital expended. This explains to some extent why the capital expenditure has increased at the same rate as the lamps connected; if we consider at what cost we can put down works at the present time to meet our present requirements, we find that by providing large generating plant our capital expenditure upon our works would be reduced by about 50 per cent., and that we are able to provide distributing mains at a cost of about 20 per cent. less than in 1894; and owing to the fact that the pressure of supply has been doubled, such distributing mains will now supply four times the number of lamps. It is therefore difficult to understand why the capital expenditure and lamps connected have increased at the same rate. The explanation is probably that the extension of works and mains has been carried out upon extensive lines to meet future requirements, and if, as I think, this is so, then further lamp connections should improve to a very large extent the results we have obtained from our undertakings.

As an actual fact I find the total capital expended upon an undertaking with which I am connected per 8-c.p. lamp was, in 1894, £3; it is now £1 5s. 1d.

The question of depreciation, which is of great importance to the numerous Electric Supply Companies, has not received the attention it should have done. Municipalities are compelled to repay their loans within short periods, and have already either repaid or accumulated for repayment very substantial sums. If we venture to look forward say fifteen or twenty years, a comparison between the results of the working of Companies and Municipal undertakings will be entirely in favour of the latter, because the interest and sinking fund charges represent approximately half the total expended upon revenue account, and if the capital is repaid, these charges will not exist. The result will be that the Municipal undertakings will be able to reduce the price charged per unit by approximately one-half, whereas, unless the Companies make more substantial provision for depreciation, their charges will have to be maintained, or the profits reduced. I do not wish to convey the impression that I think the amount annually contributed by Local Authorities to the sinking fund is sufficient provision for depreciation. They are allowed by Parliament to accumulate profit to the extent of one-tenth of the capital expended, and this should certainly be done before large sums are handed over for the relief of the rates of those who do and those who do not use electricity.

Perhaps the most interesting part of our results consists of the

figures relating to the average price obtained for the units of energy sold; we find the charges have been reduced by Companies to the extent of 2·1 pence per unit, and by Municipalities to the extent of 2·7 pence per unit, and we also find the natural result that the units sold have increased more rapidly as the price has been reduced.

The reductions in the cost of production have been due to improved load factors, caused by the introduction of electric traction, to the general adoption of electricity for motive power purposes, and the increased consumption for lighting purposes due to reduced charges, to the division of standing charges over an enormously greater output, to the great improvement in economy due to the use of larger generating plants, and to the general improvements in other departments, including that of management.

From the consumers' point of view the results should be considered satisfactory; if the latest type of lamps has been adopted, not only are they obtaining their energy for lighting purposes at approximately one-third the cost, but with the same quantity of energy they may obtain practically double the amount of light, which is equivalent to a total reduction of 66 per cent.

The conclusions which I think may be drawn from this very brief glance at the progress of electric supply undertakings are, that greater care must be exercised in the expenditure of capital, that the introduction of large generating plants will lead to ultimate economy and will enable us to compete with the comparatively small engines employed for driving factories, and that reduced charges will still further enormously increase the output of energy for both lighting and motive power purposes, if we by exhibition or other practical demonstration show the actual advantages to be derived from the use of electricity.

MANCHESTER LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

S. L. PEARCE, Member.

(*ABSTRACT.*)

November 17, 1905.

I propose at this, the opening meeting of our session, to touch briefly on some few of the recent advances made in electrical work generally, and incidentally to indicate some of the problems that yet await solution. The past year has not produced any revolutionary changes in the sphere of electric lighting, but spurred on by the competition from the gas industry, improvements have been made which tend to the cheaper production of light. The Nernst lamp has been more extensively adopted for inside lighting, and in many cases has been able to compete successfully for side street lighting with the incandescent gas mantle. The original form of this lamp, known as the "A" type, with vertical glower, up to quite recently proved the most satisfactory, and it is questionable whether it is likely to be superseded by the latest, or "D," type, which employs an enlarged spiral burner, supported in a horizontal position, and giving about 75 candle-power with an energy consumption of about 115 watts. The distribution of light from a horizontal burner is hardly as satisfactory, from a street lighting point of view, however suitable this type may prove in more confined situations. Want of uniformity is still a failing with Nernst lamps, and this is most apparent in the life of the burners, and is also noticeable in the rate at which the candle-power falls off. Owing to the burners being largely composed of magnesia salts, which have an affinity for moisture, it must not be overlooked that electrolytic action will be set up in damp atmospheres and will account for the great percentage of burner failures in wet weather.

The most striking development in the production of a more efficient incandescent lamp is the tantalum, which may be now taken as having successfully emerged from the experimental stage. The lamps are made in voltages from 50 to 120, burning in series or single parallel. A recent series of tests shows that the filament of a tantalum lamp

increases in resistance with an increase of voltage, and therefore increases with the current and temperature. This is an important point of difference between this form of lamp and the ordinary carbon filament. Consequently variations in voltage do not have the same effect in the increase of candle-power emitted—speaking roughly, it requires twice the amount of change in voltage applied to the tantalum lamp as the carbon filament lamp to produce the same change in candle-power. Fitted with clear globes, an energy consumption of 1·7 watts to 1·84 per mean horizontal candle-power and 2·2 watts to 2·47 per mean spherical candle-power was obtained. The distribution of light in a horizontal direction is remarkably uniform, and is in excess of that given by a carbon filament lamp, but in an end-on direction is less. The percentage of candle-power emitted end-on to that emitted in a horizontal direction in the case of the tantalum lamp is approximately 30. The useful life of these lamps and the reduction in light emitted do not differ materially from the ordinary carbon filament type, and the power taken during the life of the lamp is practically constant. Tantalum lamps having a 25 per cent. lower efficiency than those just described, with a reduction of some 35 per cent. in light emitted, have been produced to give a useful life of double the number of hours of burning.

Of the same order may be mentioned the osmium lamp, with an even lower energy consumption, which, as soon as the initial difficulties in connection with the weakness of the filaments have been overcome, will mark a similar advance in the production of a more efficient incandescent lamp.

The mercury vapour lamp has not met with much favour so far in this country, and the progress made in its development is so small that it can hardly be said to have emerged into a practical stage. Attempts have been made to add some red rays, but apparently with little success. A very rapid falling off in the candle-power is noticeable after a comparatively few hours of burning, which may be partly due to the deposit which is formed on the inner surface of the tube. From the point of view of mere efficiency the various forms of the mercury vapour lamp mark a distinct advancement, their radiation efficiency being five to six times that of the carbon filament lamp.

In the arc-lighting world manufacturers have chiefly given their attention to the improvement of the "enclosed" arc and the development of the "flame" arc. In the case of the former the absorption of light due to the use of a second or outer globe, and the resultant reduction in efficiency, has been responsible for the production of the type known as the single enclosure. Such a step has meant that the "enclosed" lamp will possess many of the good points of the open arc whilst retaining the special advantages pertaining to the closed type. The practical convenience of having a lamp capable of burning for at least 120 hours without renewing the carbons is obvious, and must be of great commercial value. A further result of the enclosure of the carbons is found in the lengthening of the arc, whereby the lamp can be made to take a much higher voltage across the arc, and no difficulty

is now experienced in running enclosed arcs singly on 200-volt circuits.

The improvements that have brought the "flame" arc into its present state have been directed chiefly towards simplifying the feeding devices and to the manufacture of the electrodes. These lamps have their carbons arranged either parallel or inclined towards each other instead of vertically above one another as usual, the arcs burning under a reflector, being usually controlled by magnetic influence so as to direct the light to the best possible advantage. The early defects of the feeding mechanism in this class of lamp, so as to keep the arc in a fixed position under the reflector, were responsible chiefly for the unsteady and unsatisfactory light that was produced. The impregnation of carbons with calcium, magnesium, or other salts has received considerable attention of late, and many forms of electrodes of a composite nature have been devised with the object of securing the steadiness of the arc, the lessening of the rate at which they are burnt away, the elimination as far as possible of the noxious vapours that are given off, and a lower first cost. One of the main objections to the "flame" arc is the fact that it does not admit of being enclosed, although efforts are being made to partially secure that end by the employment of magazines which shall contain sufficient carbons to obtain 50 hours of burning. The perfect magazine lamp has been coming for a long time; whether present-day manufacturers will meet with any better success than those who have previously attempted is an interesting point. The outlook, however, is distinctly promising.

Mention may be made of the interesting lamp known as the magnetite, which has been brought forward in America, wherein black oxide of iron is used as one of the electrodes, the other or upper electrode being of copper of such a section that the heat developed is conducted away as fast as it is generated; the copper, never getting very hot, therefore does not burn away. The light is emitted from the magnetite vapour formed, and the rate at which the lower electrode burns away is $\frac{1}{8}$ in. per hour. Various salts are added to the magnetite electrodes for the purpose of increasing their life, and it is said to be possible to obtain a life of 500 hours with an 8-in. electrode.

The application of the intensified or high-pressure system of gas lighting has found favour in many quarters, and is a competition that has to be seriously faced. We had an example of this only recently in London, when tenders were invited for the lighting of the new thoroughfares of Kingsway and Aldwych. With this exception, however, no town of any size appears to be reverting to gas as the result of definite comparative tests between the two rival systems. On the other hand, lighting by electricity is considerably on the increase. Special mention should be made of the present lighting of Fleet Street, London, by gas, but it is clear that this change is made only as an experiment, and cannot be possibly regarded as a case of the supersession of electricity by gas. Against this may be set the fact that the Westminster Council, after conducting extended com-

parative tests between arc lighting and the high-pressure gas systems, have entered into contracts for a considerable period for street lighting with the electrical supply companies.

One other point touching on this question of street lighting. On analysing some of the published returns for electrical street lighting it will be observed that with a system of open arcs the cost of current may be taken as varying from 50 to 60 per cent. of the total charges, and the cost of the carbons, trimming and general maintenance the remainder. With a system of "single enclosure" lamps it has been found that the cost of current is some 90 per cent. of the total, the maintenance and other charges amounting only to some 10 per cent. It is pretty evident, therefore, that any system giving long hours of burning has a great commercial value, and it is to be hoped that this may be capable of extension to "flame" arcs by the successful development of the magazine lamp.

Turning to the application of electrical power for industrial purposes we find that very considerable progress has been made during the last year. The Yorkshire Electric Power Co., the Lancashire Electric Power Co., the Clyde Valley Electric Power Co., and the Fife Electric Power Co. have commenced operations, and others will shortly follow. It is noteworthy that of the four new companies the three former are employing three-phase systems operating at 10,000 and 11,000 volts, and the latter a two-phase system at 3,000 volts. Nor have the larger municipalities been behindhand in the development of a power load at cheap rates, assisted by such means as the hiring-out system of motors and the "restricted hours supply" system at very low rates. It may, perhaps, be of some interest to state that in this city at the present time there is in use some 11,000 H.P. in motors, and the power sales for last year show an increase of 75 per cent. over the preceding year.

The adoption of electrical transmission of power for textile factories is a problem that more closely concerns us in this part of the country; but on account of the more favourable conditions for operating with steam plants, little progress has been made. This is certainly a matter for some considerable surprise in the light of data obtainable from the States and the Continent, where textile factories have adopted electrical driving extensively. On the other hand it must be admitted that if it be possible for a cotton mill, equipped with steam plant, to operate at a total cost not exceeding £2 10s. per I.H.P. per annum, it would be difficult from the point of view of economy to show much better figures than these, and some very cogent reasons in favour of electrical driving must be advanced before millowners can be expected to adopt it.

For transmission lines the use of bare copper wires has been sanctioned in the case of three or four of the power companies, and incidentally it may be stated in passing that one of these—viz., the "North Wales," avails itself of the use of water power, and will therefore form one of the very few examples of hydro-electric installations in this country. It is also of interest to note that this company,

together with the Gloucestershire Power Co., were the first to obtain Parliamentary powers to use overhead bare conductors. Taking a 6,000-volt transmission line, the cost of running three-phase mains of any given section overhead would be approximately one-half of an underground main of the same section. For a 12,000-volt transmission line the proportion would be roughly one-third only. It is evident, therefore, that this factor will have an important bearing on capital costs and the question of cheap supply of power. Long-distance power transmission work with its corollary of extra high voltages has not made much advance in this country up to the present, the highest pressure employed being 11,000 volts.

Although the last two or three years have witnessed a considerable reduction in the cost of production of electrical power on a large scale, electrical engineers should not be unmindful of the fact that there is at the present time an increasing competition for the cheap supply of power for smaller or isolated plants. For plants using up to 200 to 300 B.H.P. suction gas-producers and Diesel engines will prove keen rivals owing to their low fuel consumption. The cost of the latter per B.H.P.-hour in the case of a suction-producer has been stated to be only one-half that of Mond gas at, say, 2d. per 1,000 cubic feet. This saving will, however, be discounted in the case of the producers if the plant is subject to a variable load or run for considerable periods much below full load.

It will be conceded that where it is necessary and convenient to transmit all the power required from one point in any works, and under conditions that call for a steady load, the suction gas plant may be the more economical. But modern users of electrical power find it more economical and convenient to dispose of their power at certain specified points, so as to eliminate transmission losses and secure independent running for the various part of their factories. Then the only fair comparison to be made is between a motor-driven factory taking a public supply of energy and a similarly-equipped motor-driven factory taking a supply from its own private gas plant, and it can be shown then that the costs of production do not widely differ. But these are not the only considerations to be taken into account. There are the questions of ground space for the private plant, the expenditure of relatively large sums on same, the ability to run any particular portion of a works on overtime without running the whole generating station, which in the case of a suction plant running at anything under half load would certainly be the reverse of economical.

A steady growth in electric traction work can still be chronicled, and some idea of the extent to which electric tramways and light railways have developed may be gathered from recent published returns, which go to show that the increase in capital invested in these undertakings for the last recorded twelve months over the preceding period is represented by no less a sum than £25,000,000, and the total capital invested in electric traction stood at the end of 1904 at the figure of £107,000,000.

The series-parallel system of control up to recently was the only

one adopted successfully, but considerable developments have taken place of late in the introduction of systems embodying the principle of "regenerative control." It may be taken that the possibility of economising expenditure both upon energy and upon wheels and brakes by the use of the "regenerative principle" has been fairly clearly demonstrated, these savings being proportionate according to the undulations of the routes served. Further, the variations in the power taken by each car are not so great as with the series-parallel system, and therefore a better load factor will be obtained at the power station from a system operated "regeneratively." The outstanding matters on which engineers do not appear at present to be agreed are reliability, maintenance, and whether such systems are as favourable for "acceleration" or hill-climbing capabilities as the "series-parallel."

The conversion to electric traction of the Metropolitan Underground Railways in London has been one of the outstanding features of this branch of the industry during the last year, and numerous tube lines are in course of construction, all of which work has up to the present been carried out in the composite system, first initiated in this country by the Central London Railway Co., employing three-phase current in the line transmission and direct current on the motors. This system may be good enough for tube and suburban lines, but most engineers are agreed that it will not solve the problem of main line working. The alternative to the composite system hitherto adopted, but of which there is no example in this country—viz., three-phase currents stepped down from the pressure of the transmission lines and supplied to three-phase motors—has given satisfactory results in a good many places on the Continent, notably on the Burgdorf-Thun, Valtellina and Berlin-Zossen lines under the conditions to which it has been applied.

The impetus to this movement was unquestionably given by Finzi's experiments in Milan in 1903, and since that date there has been considerable activity displayed in Germany and the United States towards the development of the single-phase commutator motor, which in its perfected form is expected to help forward greatly the solution of the problem of main line working. This theory appears also to have appealed to one or two of the British manufacturing firms, who are now tackling the problem on similar lines. The question of a standard railway motor is of the utmost importance, and unquestioned advantages would result from a single-phase system as regards chiefly economy, reliability and simplicity of the track construction and rolling stock. As far as the motor is concerned, the essential qualifications may be taken as: (1) Ability to give a large starting effort; (2) power to vary the speed through wide limits; and (3) they should return energy to the line when coasting or stopping.

Recent developments of the series compensated single-phase motors have made them equal to direct-current motors as far as the first point is concerned, and by the introduction of a transformer between line and motor, with variable ratio of transformation, thus giving a means

of regulation between fairly wide limits without serious waste, the second requirement is satisfied. For long lines with no severe gradients and few stops the third point is not of great importance, but for short suburban lines it is of considerable moment, and up to the present this condition is not met by the single-phase motor. Although the work which has been done with one-phase commutator motors has been largely of an experimental nature and on experimental lines, the present year has seen the putting into operation of the first single-phase electric railway in the States, and it is understood that one of the English railway companies has decided on applying the same system to a portion of one of its suburban lines.

Central station engineers are gradually coming to recognise more and more the value of steam turbine plants. The more extensive adoption of these plants, the larger sizes of units used, on which so much emphasis has of late been laid in the technical press, mark the chief progress of power-station developments. Mention may be made of some extremely good steam-consumption tests that have recently been made. With units of 3,000 k.w. capacity, 15 lbs. to 15½ lbs. of steam per kilowatt-hour at full load and 16·75 at half load have been obtained. It is interesting to note, further, that steam-consumption trials conducted on turbines after having been at work for extended periods give results which show no falling off in efficiency from the results obtained on official tests. This is a point concerning which some doubts have been hitherto expressed. Reciprocating sets are still being built in larger sizes, but it is not surprising to note that the general trend is all in favour of the adoption of turbines, especially for large units.

The past year has marked a development in the design and manufacture of turbine-driven continuous-current generators. It is not so very long ago that the difficulty of solving in a satisfactory manner the commutation problem was considered a barrier to their adoption. With high speeds it is impossible to keep down the reactance voltage; with slow-speed sets, on the other hand, carbon brushes fulfil all the necessary requirements, and special means for counteracting the armature reaction are not necessary. Two methods are in vogue successfully to-day for compensating the armature reaction on high-speed sets: (1) Compensating coils wound in slots in the pole-pieces, thus neutralising the armature effect on the field; (2) auxiliary or commutating poles arranged between the ordinary poles. Both systems have given satisfactory results in practical operation, and whilst the latter is the more mechanical arrangement, the former has advantages from an electrical point of view. Another departure from generally accepted practice has been made recently in the use of carbon brushes for turbine-driven generators. Engineers have been generally familiar with the wire brushes and serrated commutators, hitherto considered to give the best results, but it must be allowed that the smooth surface commutator and carbon brushes form a far more mechanical piece of work. Such continuous-current sets provided with carbon brushes are in operation now for the first time in this

country on lighting and traction circuits. Towards this improvement the present manufacture of carbon brushes has contributed considerably. The introduction of copper, either mixed with or graded with the carbon, gives to the brush those qualities which facilitate commutation.

Enough, I think, has now been said to show the value of electrical engineering progress to the community generally, and which has brought in its trail social changes of untold benefit to mankind. In conclusion, may I express the hope that the session on which we enter this evening may be as successful as those that are past, and that the discussions of the papers presented may be mutually helpful ?

NEWCASTLE LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

W. M. THORNTON, D.Sc., M.Eng., Member.

(*ABSTRACT.*)

November 20, 1905.

In that distant time, a thousand years or so before the invention—by Hero—of the steam turbine, the most interesting study for man was man. What problems there were then of science and of art centred upon him as one engaged in a struggle with the great unknown forces of the material world. Our present knowledge of these would seem to those old-time thinkers superhuman, but the fact remains, though it is apt to be forgotten, that the true interest of it all is still in its relation to man. The wisdom and skill which are able to direct these forces of Nature on a large scale form now our wide profession of engineering, well described by Sir Oliver Lodge as "half science, half art." The science of it is a compound of mechanics, physics, mathematics, and chemistry; the art, that skill in the arrangement of materials which enables structural, mechanical, or electrical work to be carried out with the greatest efficiency and economy combined.

In every branch of engineering there are three distinct classes—proprietors, executive staff, and workmen—each of which requires suitable training. The difference between that of the first two and the last is that a knowledge of the physical laws of Nature is essential for the former, and is to be gained best by a special preparatory education. For the latter a knowledge of a few properties of matter is sufficient to be gained during the practice of the trade, and with the training of the artisan I do not propose to deal. Every opportunity is now given for talented boys to rise in any class, and the educational systems of Germany and America are good examples of how this may be done well. These countries recognised, one seventy, the other thirty years ago, the value of training those whose industry requires either advanced technical knowledge or power of adaptability. The slower movement of our industries relative to theirs has given rise to much anxious thought, and to the Mosely Commission. The result has been to emphasise the importance of having a highly skilled staff to carry out new ideas; the work goes on with so much more ease and

certainty. There is no doubt that English manufacturers know their work as well as any in the world, but it is a good thing to have a large body of trained subordinates with ideas of their own, and eager to have the chance of seeing them carried out. In this respect Germany and America have obtained a decided lead, though each system has developed faults, that of the former being overstrain, whilst in America they seem to be more eager to apply than to investigate.

Education of an Engineer.—It may be well to consider shortly the course of training which experience has shown to produce good results. One can assume that a boy desiring to become an engineer of the better sort has been to a good secondary school, and that he leaves at the age of seventeen. He should then have an adequate knowledge of his own language and at least another (French or German by preference), the elements of Euclidian and co-ordinate geometry, algebra to the binomial theorem, trigonometry to solution of triangles, mechanics of a sound, descriptive kind, and a little chemistry and physics. Those who have not been able with ordinary effort to attain to this moderate standard should be given the choice of another career. Classical scholarship can in the future only be afforded or attained by schoolmasters or men of leisure. There is certainly no greater handicap to a boy entering an engineering career than an education on the classical side of any public or secondary school. The pupil should, while his school work is fresh, be required to take the entrance examination at some university where engineering is taught, and this should be regarded as the finishing point of his school life.

One enters now upon debatable ground. Is it better to go straight from school into the works or to college? A boy fresh from school rapidly absorbs the spirit of the place in which he lives. If he is in the shops and left to himself, it is a fact that he soon takes the workman's view, and may learn to regard foremen and managers as, in a sense, his natural enemies. The effect is, however, more far-reaching. It has the tendency to set his future thinking on a lower mental plane. To have large interests and a wide outlook cannot be too early impressed upon a plastic mind, and the workman's view, judging by his talk, lacks both of these. I thought once, probably guided by my own experience, that it was well to have works before college—one knows what one ought to know so much better—but after many years of close contact with students of both kinds I have come to think that, on the whole, the gain in works' knowledge, and stimulus, is more than counterbalanced by the loss of clear thinking and recognition of first principles which prove so valuable later. In addition to this, a boy serving an apprenticeship first rarely has a chance of showing ability within three or four years; his lack of knowledge keeps him back, whilst one somewhat older and familiar with the principles and more important constructional details of the work has often an early opportunity to make a name as a keen and reliable fellow, provided that he enters the works with an open mind and is still willing to learn.

All colleges which provide a three or four years' course in engineering insist on a sound knowledge of the elements of mathematics,

physics, and chemistry. The first year is, therefore, almost entirely occupied with learning or revising these, a few descriptive classes and some geometrical drawing being added for stimulus. If possible, mathematics should be continued through all three years. The power of facile thinking with abstract quantities, though it may rarely have direct expression in after-life, is of immense service to engineers. The higher laws of heat and elasticity and electricity, and the simpler quantitative and more advanced descriptive treatment of technical subjects, will form the second year's course. That of the third year is almost entirely technical, and of such an order that a student should have little difficulty on its completion in judging for himself the significance of any new suggestion or advance in practice or theory. A fourth year may well be occupied in experimental work on new ideas.

Technical or "bread" subjects, as the Germans call them, have only within this last year been recognised by Government as having educational value, and the rise of the demand for higher technical education is an interesting study. It is a well-known fact in the history of education that "A new standard or fresh subject of education is impossible without the strong impulse of social or professional interest."* The Elementary Education Acts were a direct outcome of impulses of the first kind, the recent change in the attitude of the authorities towards engineering departments in university colleges is of the second. Without the strong backing of professional interests, medical, engineering, or chemical, university colleges would long ago have degenerated into high schools.

Civic patriotism has played a large part in the development of the wider educational ideals. In Liverpool there are twenty-five departments in the University, each endowed with £10,000. Manchester, Birmingham, Leeds, and Sheffield can all show like results. We are rather isolated here in Newcastle, but we shall no doubt in time feel the wave from the centre of activity further south. Perhaps we are stunned by the shock of Mr. Carnegie's gift of £2,000,000 to Scotland. Since 1870 the growth of industry upon Tyneside has been phenomenal. Shipbuilding and all branches of engineering are to be found here in highest activity, and it is not too much to say that Tyneside owes an appreciable share of its success to the high standard of training maintained by this college throughout the last thirty-four years. Notwithstanding this, we have no permanent endowment for any one of our twenty departments.

The most rapid and fruitful return for endowment is in the field of research. It is now generally agreed that the function of a university establishment is both to teach and to extend the boundaries of knowledge. Scientific research falls under two heads. There is, on the one hand, that close study of facts more or less known in order that accurate information may be had for industrial purposes. This is embodied in the National Physical Laboratory, which, being supported by public funds, directs its attention to work of im-

* W. H. Woodward, "Erasmus Concerning Education," p. 85.

mediate industrial value. On the other hand, there is speculative search into the unknown on lines suggested by unique chains of thought, arising from new observations or strong co-ordinated thinking. Work of this latter kind cannot be undertaken to order. There are times of inventive activity in which ideas come rapidly, then follows the patient experimental search for truth where so many fall out. Now if it is to come at all, a time of speculative activity almost inevitably follows the completion of a university course. It is then that encouragement and, perhaps, pecuniary help are of vital importance to a young student. He should have the opportunity of seeing how to carry out ideas by watching or helping in the research work of his professor, and the advantage is mutual.

There is in connection with experimental research a disregard by many, though not all, manufacturers of much promising material. We take our young engineers from college and put them for years to routine work which untrained men do as well or better, and are disappointed that they do not show striking results, forgetting that two things are necessary to progress—the man and the opportunity. I would suggest that men with a first-class college record should, instead of being treated as beginners, be taken into the confidential departments, design or test room, and set to work on new things, at first under supervision. Of course, if there are no new things to work at, the industry is stationary or retrograde. They say no man becomes a good glass-blower until he has broken 10 lbs. of glass in the process of learning. There should also be some similar allowance made for crude ideas in engineering—say, ten pounds sterling. Fuses cover a multitude of sins in the test-room, and it would take a good deal of work to reach this limit. In a large industrial centre where there is, as here, close relationship between college and works, I would suggest that where there are not men and instruments available in the works, senior students should be lent occasionally to do a week's work—say, with an oscillograph on wave-forms, or on the effects of armature reaction, or in studying interpolar induction or commutation in special cases.

Research and Practice.—The interdependence of science and industry has been a fruitful theme for a hundred years. One never knows to where an experiment a little off the beaten track will lead. I have recently had a good example of this, on a small scale, which may be of interest to you. Some years ago I made a few experiments upon bacteria, working mostly with typhoid germs on account of their sensitiveness. During these I found that M. Lortet had discovered what I was looking for, that alternating currents cause them to orientate and place themselves along the lines of flow, but he failed to find any effect with direct currents. As a matter of fact bacteria of all kinds, living or dead, orientate in the same way under either direct or alternating electrification.

On thinking over the cause of this, it was found that the movement depended entirely upon the relative conductivity of the organism and the surrounding liquid. So that the former behaves as a rod of iron

in a magnetic field, or one of a dielectric in an electrostatic field, the same laws governing lines of stress or steady flow whether of electricity, magnetism, heat, or liquids. In searching for the cause I found that glass orientates in oil, but not in water, and that carbonised silk filaments are very sensitive in either. Some time after I wished to design an apparatus to indicate the state of charge on cables, in order to see whether they were safe to handle. The simple electroscope was first thought of, but rejected as not mechanically strong enough to be placed in a platelayer's hands. It then occurred that one might use the same thing on a small scale, observing the movement in a kind of linen-tester's microscope. On trying this I noticed a small spark pass between two particles of carbon suspended in oil, and the idea at once came, "Why not look for the sparks?" In ten minutes or so after this the first "voltascope" was made and tried on a 2,000-volt circuit, and a little while later on 20,000 volts. The instrument as it is now made consists of a glass tube containing oil and short fine carbon rods. Contact is made across the mains through a heavily-insulated wire having an ebonite or fibre handle with sharp steel points to get good contact. It works equally well with direct and alternating currents, and in any position. As soon as contact is made the carbon filaments become polarised and form an irregular chain, along which a small current passes, jumping across minute gaps between the particles, and so forming sparks which are instantly extinguished by the oil, their constant appearance and extinction giving the tube the effect of scintillation. The working range of the instrument is from 10 volts upwards.

It is a far cry from bacteria to an electric life-saving device, but the same line of thought led further to the invention of the high-tension voltmeter shown. So far as I know, this differs from other forms in the use of a *dielectric* needle or quadrant. A short ellipsoid of paraffin or sealing-wax is suspended by a fine silk or quartz thread between brass plates, contained in a glass globe about 15 cm. diameter. Theory indicates that the torque on the suspension is proportional to the square of the voltage, and this is found to be experimentally true. One uses the instrument in the same way as a Siemens dynamometer or the Ayrton-Mather voltmeter of the same type. The ellipsoid is brought to a balanced position between stops by rotating the torsion head. The lowest voltage to which it is sensitive is about 500, and I have used it to measure spark-gap voltage up to 100,000. Since specific inductive capacity varies with frequency, a simple correction must be applied for this.

There is a still further extension of the same theme. One can measure the permeability of iron by the torque on a long ellipsoid suspended in a magnetic field, and in the same manner one can determine by this instrument the dielectric constants of all solids, liquids, or gases when a litre of the latter can be obtained. The effect is a function of the relative permeabilities of ellipsoid and medium, and a comparative series may be readily formed and checked by reference to air. The ellipsoids must be made very carefully, and Messrs. Hilger can be relied on to do this.

These examples, given for what they are worth, serve to show that a little research with a microscope may lead to results quite unthought of at the time in an entirely different subject and on a different scale. The microscope might be much more used in electrical engineering than it is at present, if, indeed, it is used at all. We know now that the permeability of iron depends upon the size and distribution of the crystals of carbide of iron in the metal, and that these are changed by the heat treatment this has received. Why should we not estimate permeability by polishing a surface on the metal, observing it through a microscope, and, if necessary, photographing it? After a time, by collecting a set of standards, the quality of any specimen might be assigned in a few minutes by inspection. We have timber merchants selecting wood by inspection of the grain; why not makers of machines selecting magnetic iron in the same way, and requiring ironmakers, when quoting, to send a micro-photograph of the material?

In the heavier branches of electrical engineering, workshop research can show many examples of important results reached by following side-tracks, but to carry out research work with any chance of achieving a definite advance, there must be sound preliminary training, and thus we return to the first theme of education for those who will be in a position to do or direct it. There are, we may be sure, hidden in the future, advances in science and practice fully as great as those which we have inherited and which have come to pass in our day. They will come from patient search in workshop, laboratory, and study, by those men who are, as it were, the growing points of science, thrusting down into fresh, dark, fruitful soil the roots by which the spreading tree of knowledge is upheld.

MANCHESTER LOCAL SECTION.

STREET LIGHTING.

By Haydn T. Harrison, Member.

(*Paper read December* 12, 1905.)

To write a paper on street lighting in general would require a long search into history before it would be possible to give any explanation as to how it came about that the streets of our towns are lighted in the way we find them. But I do not propose to attempt to solve this mystery, beyond stating that, after the decade of oil lamps, when it was decided to use gas lamps, these must have been in a large number of cases erected indiscriminately, depending upon the sum of money at the disposal of the authorities. It is probable that in some instances the surveyor may have had a say in the matter, but, judging by results, I am forced to the conclusion that he was generally overruled by some body of gentlemen who, very likely, formed themselves into a Street Lighting Committee, and under that august name went about planting lamp-posts at random.

This practice, I believe, still exists, and what is even more striking is that you find the same collection of gentlemen, who include in their numbers representatives of all professions and trades, taking upon themselves the duty of deciding on the merits of various methods of street lighting, and when you ask them what they know about the matter, they answer that they represent the "man in the street." This answer naturally leads to another question: Why does the "man in the street," who we will take for granted is a ratepayer, allow you to retain the services at his expense of a surveyor and engineer to advise you on the subject if their advice is not to be taken? The reply to this question is not so prompt, but very generally amounts to the fact that the gas company's engineer, or representative, told them that the reports they had received from these gentlemen were all nonsense, and that they had better go by their own eyes; thus the well-known proverb of the prophet in his own country is verified once more.

Everyone can judge illumination with his own eyes, but, in order that his judgment may be of any practical value, his eyes will require assistance in the form of a photometer. Both gas engineers and electrical engineers are taught to use this instrument,

but I have never heard that its manipulation is included in the education of any one belonging to the professions and trades from which the representatives of our boroughs, cities, or towns are generally drawn; therefore, if the engineers could be persuaded to use photometers for the purpose of measuring illumination which cannot be accurately measured in any other way, and if committees could be persuaded to make use of these measurements when they are made, the result would be that the ratepayers would benefit, not only financially by the reduction of the lighting rate, but also by the increased comfort which would result from the better illumination of the streets.

The antipathy which engineers have so far shown to the actual measurement of street illumination is in the case of gas engineers, and to a smaller extent in the case of electrical engineers, due to the fact that they are in the habit of stating the value of a lamp as the candle-power which it will give when measured in the best position and without any globes or lanterns; therefore, when measuring street illumination, a figure is generally obtained much lower than that claimed; but it is this actual figure which must be used for comparative purposes, and, as I have suggested above, electrical engineers have much less to fear than gas engineers from this exposure.

For instance, a Welsbach mantle consuming from 3·5 to 3·75 cub. ft. per hour is generally stated as 70 c.p., whereas the very large number of measurements I have made during the last few years have shown that the average candle-power derived, when measured in the street, is 35! Again, a 200-volt, ¼-ampere "A" type Nernst lamp, according to the makers, gives 70 c.p. (heffner units), and in practice I have found them equal to 37 c.p.!

Again, a 500-watt, direct-current, open-type arc lamp is generally called a 1,000-c.p. lamp; whereas Mr. Bradley's tests and my own go to prove that they average 600 c.p. Another example is the new gas lamps in Fleet Street, which were claimed as 200 c.p., whereas the actual measurements I have made prove that they average 135 c.p.

Another example is the much-advertised gas lighting in Kingsway and Aldwych. The gas journals are continually referring to the lamps used as 1,000 c.p., whereas the average of a large number of photometric measurements made by myself and others prove that the average candle-power in the street is 515.

I think these examples sufficient basis for the opinion I have formed as to the reason why gas engineers avoid the photometer and prefer to rely upon verbal or written statements which they trust never to be called upon to verify.

I do not wish you to go away with the idea that I place *no* value on public opinion of street lighting; I know that the residents in any town or street could tell you whether its illumination is sufficient for their purpose, because they have to use the light and judge accordingly. But to take any individual and ask him to give an opinion on the value of two illuminants—which do not, probably, vary more than 50 per cent.—is pure waste of time, unless he uses suitable instruments, or has made a special study of the subject.

In order to arrive at any decision as to the degree of illumination which may be considered efficient for various streets it is necessary to decide first the units in which the value of illumination should be specified. I have had the opportunity of examining several reports which have been submitted by engineers to Lighting Committees; in the majority of these it has been considered sufficient to state the candle-power of the lamps in the same way as Mr. Bradley does in the most valuable tests he makes periodically in Westminster; others have gone a little further, inasmuch as they state the candle-power per mile of road; others, again, have based their figures on various illumination tables given in candle-power feet at various distances from the source of light.

That none of these methods are complete enough will be obvious when an attempt is made to compare the reports. For instance, the mean illumination of a street cannot be ascertained from measurements of candle-power unless these are taken at a large number of different angles, because there is practically no source of artificial light which gives a true hemispherical candle-power; by that I mean a light of which the candle-power measured at any of the angles in the lower hemisphere will be approximately equal. Moreover, it is necessary to state the height and distance of the lamps, in order to judge the illumination derived.

In 1892 Mr. Trotter read a paper * which dealt very fully with this matter, and his paper is even now probably the most complete treatise extant on the subject. Many members will remember Mr. Trotter's paper, and no doubt use it for reference, but for the benefit of those who have not seen it I propose to give a short *résumé*, in order that I may point out the reasons which, in my opinion, have prevented his proposed system of measurements from becoming generally adopted.

Mr. Trotter used an illumination photometer devised by himself, in conjunction with Sir William Preece, by which the horizontal illumination at various parts of the road could be measured; and incidentally he gave it as his opinion that the nearer this illumination could be measured to the road surface the better.

Now, it is obvious that if the degree of illumination is measured on a horizontal plane, all the lamps in the neighbourhood of the photometer will assist in illuminating that plane, therefore the spacing and height of the lamps can be disregarded when making comparison, and only the measurements in candle-power feet taken into consideration; and if the mean of these measurements could be taken as a criterion of the illumination of the road, no better system could be adopted. Mr. Trotter shows at great length in his paper how this can be done by plotting a large number of contour curves and illumination curves along imaginary lines drawn down a street; but unless sufficient measurements are made to plot these curves in every case, and a mean illumination obtained by dividing the plan of the street into a large number of sub-divisions and taking a mean of all the various degrees

* *Minutes of Proc. of Inst. of Civil Engineers*, vol. cx., 1892, p. 69.

of illumination in all the sub-divisions, as shown by the contour curves, I fail to see how the mean degree of illumination can be arrived at.

As the above process would entail more time than can generally be given to this branch of work, I would not advise anybody to attempt it. Moreover, there are other practical objections to the use of an illumination photometer as described by Mr. Trotter, which eventually resulted in my abandoning its use, but not until I had had practical experience of it for a period of about two years, and had obtained results of considerable value to me in my study of street lighting.

These practical objections were the following:—

The large difference between the maximum and minimum illumination when measured on a horizontal plane, coupled with the small range of the instrument, made it only possible to survey the illumination over a very small portion of the street unless several different standard lamps are used, and even then the instrument was found to be difficult to balance when a comparatively high or low degree of illumination was being measured.

Thus I came to the conclusion some time back that in order to encourage more general testing of street illumination for comparative and specification purposes, a simpler means would have to be adopted than has hitherto been the general practice, and that an instrument must be devised by which the degree of illumination of a street could be rapidly and accurately determined. I am now able to show the design of instrument I consider most suitable, but, before discussing it, I propose to define the measurements which I have come to the conclusion are necessary.

In order to judge the lighting of a street it is only necessary to know the minimum illumination at any point where light is required, because if that illumination is sufficient for the purpose it obviously follows that it will be ample elsewhere; to go to great trouble in order to obtain an average illumination is not only sheer waste of time, but also misleading; for example, the average illumination of a street brilliantly lighted in one part and left in comparative darkness in another part may be high, but it is of no practical use except that you know that by moving from one brilliantly lighted spot to another you will travel along the street, provided you do not encounter any unseen objects or dangers in the dark intermediate parts; therefore, I think you will agree with me in saying that the measure of minimum illumination is of primary importance, and on its value the efficiency of the lighting of the street depends.

It will probably be suggested that the value of the maximum illumination should also be measured and stated, in order that a diversity factor may be arrived at. This is to some extent true, as passengers in vehicles passing rapidly along a street having a large diversity of illumination are liable to become dazzled; moreover, the value of the minimum is reduced if the iris of the eye is being periodically contracted by brilliant patches of light. Therefore, I think we may take it that the best-lighted streets are those with the highest minimum illumination and with the lowest diversity factor, and, after having

granted this definition, all that remains to be done in comparing the lighting of various streets is to state the value of the maximum and minimum illumination as measured therein.

But the unit of illumination, namely, the candle-power foot, is not sufficiently definite, for it is obvious that when speaking of illumination we really mean the degree to which something is illuminated, and that will depend to a very large extent on the average angle at which the light strikes the various surfaces of that object.

Mr. Trotter, with his illumination photometer, chose to measure illumination on a horizontal surface, and it has become very common to state (as Mr. Hoadley did in his paper read before the Municipal Electrical Association this year) the measurements in candle-power feet, disregarding the angle of the screen on which the illumination was measured.

I have, therefore, prepared the following Table (I.) of illumination on planes at various angles to demonstrate the error which might follow if this important factor in the unit is disregarded. This table also emphasises the decision to which I have come regarding the most suitable angle of the screen on which to make these measurements.

For the sake of simplicity I have taken the light as being 1,000 c.p. in all directions and at a height of ten feet above the measuring screen:—

TABLE I.

Illumination in C.P. Feet on Screens Fixed at Various Angles.

Distance in Feet.	Direct.	Horizontal.	Vertical.	At 45°.
0 Illumination...	10	10	0	7·70
5 " ...	8·0	7·15	3·5	7·0
10 " ...	5·0	3·5	3·8	5·0
15 " ...	3·0	1·7	3·5	2·9
20 " ...	2·0	·89	3·1	1·88
30 " ...	1·0	·31	1·7	·88
40 " ...	·58	·14	·57	·5
50 " ...	·38	·075	·26	·32
60 " ...	·27	·044	·19	·2
70 " ...	·20	·028	·15	·158
80 " ...	·15	·019	·12	·120
90 " ...	·12	·013	·098	·094
100 " ...	·09	·001	·081	·076

It is, of course, unnecessary to remind the members that the illumination of a surface is proportionate to the candle-power of the light divided by the distance in feet squared which separate the light from the surface; this unit is described as candle-power foot, but it *may* be necessary to remind you that, unless otherwise stated, it is assumed that the illuminated surface directly faces the source of

light, in which case the angle of incidence is o; at any other angle the illumination of that surface would be reduced in direct proportion to the cosine of the angle of incidence; therefore, it is necessary that, if any measurements are made on an instrument having a measuring screen which is horizontal or vertical or kept at a fixed angle, such a fact must be stated in order that the measurements may be of value. In order to avoid the necessity of making such a statement, the obvious inquiry is—why not design the instrument so that the direct illumination is always measured? My answer to this is that it requires another adjustment every time a measurement is made, thus not only complicating the design of the instrument, but also increasing the time occupied in making the tests.

It will be noticed that in the design of instrument I recommend an angle of 45° has been chosen; if it had not been for practical reasons I would have preferred a vertical screen. My reasons for abandoning the horizontal screen, which I used for many years in a type of instrument similar to that suggested by Mr. Trotter, may interest you; one reason was that the angle of incidence when measuring at a distance from the post became so large as to reduce the illumination on the screen to that point when it was difficult to get a balance, and, moreover, unless the screen was accurately levelled, considerable errors were liable to creep in; these faults made it practically impossible to measure the minimum illumination, which I consider the most important factor. For instance, at 100 feet from a post 20 feet high on which is mounted a 500-c.p. lamp the illumination on the horizontal screen used in the instrument would only amount to 0·005 c.p. feet, whereas if the screen had been illuminated by direct rays it would have been 0·045, which is nearly ten times as much, and could have been easily measured. With the instrument shown here it is equal to 0·04, and can be measured with ease and accuracy. With a vertical screen it would have been equal to 0·047, which would have been even more easy to measure; but, on the other hand, it is obvious that directly under the post the vertical screen would be useless, and the illumination on the horizontal screen would be so high as to be out of the range of the instrument; this alone is one good reason for the use of this particular angle.

But there are two other reasons which I consider of equal importance; one is that, owing to the great variation in the spectrum of lamps used for street-lighting purposes, a flicker method of obtaining a balance is essential for accurate work, and an angle of 45° is found more convenient in the design of this part of the apparatus; the other is that the illumination of vertical objects in a street is of equal, if not greater, importance than that of the road and pavement; for instance, it is of more importance to be able to recognise faces and avoid obstructions than to be able to distinguish the quality of the road; it is true that in the case of road vehicles, particularly motor cars, the latter is of importance, but as these vehicles very generally carry lamps of higher candle-power than the street lamps, the comfort of the pedestrian is more to be considered. Therefore, by stating the value of the illumina-

tion on a screen at an angle of 45° we are probably giving the most useful information for practical purposes. Moreover, the measurements obtained at this angle are as easily converted to measurements of candle-power as would be the case if any other angle were used, and the fact that the candle-power of the lamps in one direction only is measured simplifies this calculation considerably.

There is still another factor which must be stated, and that is the height at which the measurements are made from the ground; this should be settled by the most convenient height for making the measurement, which I have found to be 4 ft.

Therefore, for the purpose of measuring and comparing the illumination of streets, roads, or open spaces, I would suggest that the minimum and maximum illumination, which can be derived at any point, be stated in units of candle-power feet measured on a plane surface inclined to the vertical at an angle of 45°.

Having decided a definite means by which the lighting of streets can be accurately and rapidly compared, I have, from various published statements, obtained the opinions of gas and electrical engineers as to the present-day requirements in this direction, and, from tests made by myself and others, am able to give a rough average of what actually occurs in practice.

Birmingham.—The opinion of Mr. John Price, of Birmingham, was published in the *Street* (February, 1905), in which he stated that incandescent gas burners consuming 3·5 cub. ft. per hour—for which he claims 42 c.p. when new—should be erected at 50 yards apart in the suburbs and 28 yards apart in the centre of the city; in the very important thoroughfares two, or even three, burners may be used. This works out as follows:—

Centre of City, 80 c.p. at 84 ft. apart, minimum direct illumination, 0·046.

Main Streets, 40 c.p. at 84 ft. apart, minimum direct illumination, 0·023.

Suburbs, 40 c.p. at 150 ft. apart, minimum direct illumination, 0·007.

Partick.—Mr. Maxwell, in his paper read before the Glasgow Local Section * in 1905, stated that the 12½-ampere open-type arc lamps (for which he claimed 870 mean spherical candle-power) when fixed on posts 60 to 80 yards apart in the main streets, and 100 yards apart in side streets, were satisfactory in practice. In certain instances an average distance of 110 yards apart and a maximum of 180 yards was permissible. Allowing that the candle-power of the lamps at, say, 15° from the horizontal would not exceed 600, this works out as follows:—

Main Streets, 180 ft. apart, minimum direct illumination, 0·071.
„ 240 ft. apart, minimum direct illumination, 0·04.
Side Streets, 300 ft. apart, minimum direct illumination, 0·026.
„ 540 ft. apart, minimum direct illumination, 0·0082.

* *Journal, Institution of Electrical Engineers*, vol. xxxiv., 1905, p. 729.

Bradford.—The Gas Engineer of Bradford reports in the *Street* (January, 1905) that the principal streets are lighted with two incandescent gas lamps placed on both sides of the street 30 yards apart; he claims that they give an actual light of 100 candles—if this is the case, we may take it that the principal streets are illuminated as follows:—

Two Gas Mantles 100 c.p., 90 ft. apart, minimum direct illumination, 0·047.

St. Pancras.—The original 10-ampere open-type arc lamps were erected in the main streets at 330 ft. apart, but even in the less important streets they are now put at 165 ft. apart. The side streets were, and are in some cases, illumined with single gas mantles at 120 ft. distance. I think we may take it that the modern practice will be maintained. The results are as follows, taking the candle-power of the arcs at 15 below the horizontal as 500:—

Main Streets (old practice), arc lamps 330 ft. apart, minimum direct illumination, 0·017.

Main Streets (new practice), arc lamps at 165 ft. apart, minimum direct illumination, 0·07.

Side Streets, incandescent gas, 120 ft. apart, minimum direct illumination, 0·0095.

Croydon.—From Mr. Cramb's interesting tests embodied in a Report submitted to the Corporation of Croydon in July of this year, it transpired that the main streets were lighted by arc lamps giving an average candle-power of 450 at 65 yards apart, and the side streets by single incandescent gas burners, of which the best examples gave 52 c.p. fixed 80 yards apart, and by Nernst and incandescent lamps (the latter being fixed with Reason reflectors), which gave an average of 57 c.p. and were fixed at a distance of 66 yards apart, the results being as follows:—

Main Streets, arcs, 450 c.p., 195 ft. apart, minimum direct illumination, 0·043.

Side Streets, gas, 52 c.p., 240 feet apart, minimum direct illumination, 0·0036.

Side Streets, electric, 57 c.p., 198 ft. apart, minimum direct illumination, 0·0056.

Willesden and Barnes.—As an example of residential suburban lighting I would take Willesden, where the main streets are lighted by means of 10-ampere open-type arc lamps, 78 yards apart, and the side streets by incandescent gas burners, consuming 3·2 cub. ft. of gas per hour, averaging 50 yards apart; and also Barnes, which is lighted to a large extent by ½-ampere Nernst lamps erected at 60 yards apart. The results of these two places work out as follows:—

In Willesden, *Main Streets*, arcs, 234 ft. apart, minimum direct illumination, 0·035.

Side Streets, incandescent gas, 150 ft. apart, minimum direct illumination, 0·005.

In Barnes, Nernst lamps, 180 ft. apart, minimum direct illumination, 0·005.

Maidstone.—As an example of a town with a population of about 35,000 I would take Maidstone, where the High Street is lighted with open-type 500-watt arc lamps at 40 to 45 yards apart; in the main streets these lamps at distances varying from 60 to 65 yards are used; and the side streets are illuminated with ½-ampere Nernst lamps at 50 yards apart. Thus we get :—

High Street, 500 c.p., 130 ft. apart, minimum direct illumination, 0·11.

Main Streets, 500 c.p., 190 ft. apart, minimum direct illumination, 0·054.

Side Streets, 40 c.p., 150 ft. apart, minimum direct illumination, 0·007.

Tonbridge.—This is a good example of a town of about 13,000 inhabitants, the lighting of which has received considerable attention of late. The High Street is provided with 500-watt open-type arc lamps at an average of 90 yards apart. The residential main roads are lighted by two ½-ampere Nernst lamps on posts erected 70 yards apart, and single ½-ampere Nernst lamps also 70 yards apart. The other parts of the town are lighted by incandescent gas lamps, at an average distance apart of 70 yards. This works out as follows :—

High Street, 500 c.p., 270 ft. apart, minimum direct illumination, 0·027.

Main Streets, 40 c.p., 210 ft. apart, minimum illumination (direct) 0·004.

Side Streets, 30 c.p., 210 ft. apart, minimum direct illumination, 0·003.

Manchester.—From the valuable tests taken by Mr. Pearce here I have extracted the following figures, which give an example of the lighting of main thoroughfares of an important town :—

Position.	Lamp.	Distance Apart.	Minimum Direct Illumination.
Piccadilly	900 watt enclosed arc ...	76 ft.	0·62
Sackville Street ...	Intensified Gas... ...	58 „	0·38
Albert Street ...	600 watt enclosed arc ...	57 „	0·54
All Saints'	Intensified Gas... ...	102 „	0·14
Piccadilly	600 watt enclosed arc ...	66 „	0·30
Cheetham Hill Rd....	Incandescent Gas ...	206 „	0·013

Gorton.—A much more interesting example in this neighbourhood is Gorton, where Mr. Pearce has lately replaced 25 double Welsbach mantles, each taking 4 cub. ft. of gas per hour, by 22 enclosed arc lamps giving 400 c.p. each. The gas lighting in this case used to cost £150 per annum; the electric lighting is done for £176. Taking an average candle-power for the gas lamps based on the figures given by Mr. Price, of Birmingham, and measurements made by myself elsewhere, the candle-power will work out at 80 per post; therefore it will

be seen from the following figures that the minimum illumination has been increased four times at an extra cost of 17 per cent. per annum :—

Old System. Incandescent gas, 80 c.p., 90 ft. apart, minimum illumination (direct), 0·037.

New System. Enclosed arc lamps, 400 c.p., 100 ft. apart, minimum illumination (direct), 0·145.

As a final example, I propose to take the much disputed City and Kingsway lighting. In the case of Kingsway, the length is 4,000 ft. and the breadth 100 ft.

Kingsway.—There are 51 high-pressure gas lamps, and the measurements I had made in October averaged 670 c.p. on the lamps in good condition, and 450 on those which were in poor condition. The posts are staggered, therefore the maximum distance from any post would be 46 ft., where you would be deriving light from three sources, two of which would be available on a screen at an angle of 45°, but, for the sake of comparison, I propose to consider one only. This works out as follows :—

High-pressure gas, 515 c.p., 80 ft. apart, minimum direct illumination, 0·206.

City, Fleet Street.—Here, as you are no doubt aware, twelve 10-ampere lamps in muranese globes have lately been replaced by thirty-four pairs of incandescent gas mantles. I have tested both of these illuminants, and am able to place before you the following figures, which require a little explanation.

In the case of the gas lamps the two mantles are placed side by side, therefore the minimum candle-power measured is across the road, where it averages 80 c.p., and this will be the point at which the minimum illumination occurs, namely, at a distance of 30 ft.

The old arc lamps were at a distance of 137 ft. apart, and as they gave 680 c.p. when measured at a distance of 30 ft., it can be taken for granted that 600 would be a safe average to take at the greater distance. The comparative figures would then be :—

Old arc lamps, 137 ft. apart, minimum direct illumination, 0·117.
New gas lamps, 48 ft. apart, minimum direct illumination, 0·08.

The actual minimum illumination between the gas posts would be :—

48 ft. apart, minimum direct illumination, 0·18.

I think I have now stated sufficient opinions and examples to give you some idea of both the past and present practice; these very figures show the diversity of opinion, as demonstrated in practice. It is therefore only possible to obtain a rough average, but nevertheless this will form some basis to work on.

I do not propose to consider the more brilliantly lighted streets of Manchester, or the Gas Company's latest show in Aldwych and Kingsway, as there is little doubt that the illuminating of public buildings in the case of the former has been aimed at as much, if not more, than lighting the streets; and the latter case, as far as one can judge,

is an advertisement for the gas companies, the cost of which will probably never be disclosed. Therefore, I think we may take it that in most towns the minimum direct illumination is as follows :—

Main Thoroughfares, minimum direct illlumination,				0·050 c.p. ft.
Side Streets	„	„	„	0·025 „ „
Suburban Streets	„	„	„	0·005 „ „

These figures, I need hardly remind you, are averaged from actual measurements made in the street, and not from the fictitious values often claimed, and it is interesting to note that in many places where electric light has been installed—such as St. Pancras, Maidstone, Partick, etc.—these values have been exceeded, whereas the actual illumination obtained from gas mantles is generally much lower than that estimated by the representatives of the gas industry.

In the case of the less populated towns it will be found that the main streets are generally on a par with what I have termed the side streets of a large city, the other streets being equivalent to the suburban streets; but in many instances, such as Tonbridge, the lamps in the less important side streets can hardly be said to illuminate them at all, owing to the long distance apart at which they are placed.

Proportioning of Street Illumination.—I have never been able to find any particular law governing the decision of the powers which settle the extent to which a street should be lighted; there is little doubt that street lighting originated in a desire to prevent crime; if this had been carried to its logical conclusion, the slums and alleys of our cities would be better lighted than the parts occupied by the more peaceful, law-abiding citizens, which is certainly not the case. It might be suggested that it is proportioned in some way by the rateable value of the houses forming the streets, but I should have thought it would have been more logical to have considered the number of people living in a street, rather than their individual wealth. The people most fitted, in my opinion, to settle the matter are the police, because upon them depends the control of the traffic, the prevention of accidents, and the reduction of crime.

And now let us see what the value of the minimum illumination is; the usual test is the possibility of reading a Bradshaw railway guide. I find, personally, that this is possible at an illumination equivalent to 0·05 c.p. foot. With 0·005 c.p. foot you cannot recognise a face; in fact, can only just avoid running into anything. Mr. Trotter took for his comparison moonlight, which he found to be 0·028 c.p. foot in England near full moon; thus it will be seen that in the side streets of large cities the minimum illumination approaches full moon, but in the suburban street is less than one-fifth. I would therefore suggest that, unless the value of illumination in any streets exceeds, say, 0·015 c.p. foot, it could hardly come under the head of street lighting, but should be called "beacon lighting," as suggested by Mr. Trotter.

Methods of improving Street Lighting.—The remainder of my paper I propose to give up to discussing the possibilities of improving the existing state of affairs without increasing the cost in any way,

and the only unit I propose to consider is the minimum illumination derived at any point. It is now several years since I came to the conclusion that the efficiency of street lighting must be judged by the minimum illumination derived at any point, in the same way that the strength of a chain is decided by its weakest link; in fact, the lighting of a street is similar to a chain of links, and in order to strengthen these links at their weakest point, I devised fittings to increase the light at that point. By far the most efficient of these, which is fully protected, is now being manufactured by the Reason Manufacturing Company, of Brighton, and, as it will enter largely into the figures I propose to put before you, I will describe it in order that you may see that the excellent results, which I am able to guarantee, are obtained by utilising the rays of light which would otherwise be lost. I might mention that there are several thousands of these fittings in use, and that they have been the means of obtaining the street lighting contract for the Electricity Department in many cases.

These fittings are arranged in many different forms to suit special positions, but by far the most efficient is the one which is intended for straight roads, for which the bulk are required.

In designing these fittings, I took the following facts into consideration:—

1. That the rays directed above the horizontal are useless, and therefore can be diverted up and down the street to increase the distant illumination.

2. If the posts are erected on the edge of the footpaths, the rays which would illuminate the adjacent houses or fields are practically useless, unless the houses have a reflecting value, which is very rarely the case.

3. The rays of light illuminating the street near the post should be of small value compared to those directed to a distance up and down the street, in order to obtain even illumination.

The above conditions, in short, mean that practically only a quarter of the mean spherical candle-power is useful, and that the other three-quarters are wasted unless directed into the required direction. The extent to which this fitting succeeds is as follows:—

The average candle-power of the lamps measured from all parts of the street will be found to be 2·2 times the mean spherical candle-power, and the maximum candle-power measured over the width of the road some distance from the post is nearly three times the mean spherical, the minimum candle-power measured adjacent to the post being equal to the mean spherical candle-power of the lamps.

One-half of the filaments or glowers of each of these lamps is enclosed in a specially-shaped hollow hemispherical reflector, fixed at such vertical and horizontal angles that in those positions (as viewed from the street) where the reflectors are not in themselves increasing the illuminating value of the lamps to more than double the maximum of one lamp, the light of both lamps is allowed to shine. Thus, at no point does it decrease the light, and over the greatest area of the street the light is increased to the maximum above stated.

These reflectors are of glass blown on to a mould of the correct shape, and in such a way as to form a bottle, the inside of which is silvered; the opening is then hermetically sealed when fixing the cap; thus a reflector of about 88 per cent. efficiency is obtained—which efficiency is practically permanent.

You will note that in the reflector the whole of the hemispherical rays are deflected, whereas in previous designs in which the lamp passed through a hole in the centre of the reflector a great number of these rays were not utilised. Another point is that the lamps are in such a position that the maximum rays are used both in illuminating the distant parts of the street direct, *and* by means of the reflector.

Table II. gives the average multiplying power of the author's reflector fitting as made by the Reason Manufacturing Company, the unit of light being taken as the mean spherical candle-power of the two lamps used in the fitting; the angles at which this factor is given being the useful angles for street lighting; 0° horizontal coinciding with the kerb of the pavement.

TABLE II.

Vertical Angle.	Horizontal Angles.	Multiplying Factor.
30° (from horizontal) ...	90° (across street)	1·05
" " ...	70° "	1·5
15° " ...	50° "	2·3
" " ...	30° "	3·0
" " ...	10° "	3·0
" " ...	0 (kerb line)	3·0
" " ...	10 (house side)	1·6
30 " ...	30 "	0·85
" " ...	50 "	0·6

It will be seen from this table that, provided the lamps are adjusted correctly in the reflectors, the increase of street illumination derived by the use of the reflector fittings will be much higher than claimed, but taking into consideration extra globes, etc., the maximum multiplying factor can be taken as 2·5.

These fittings are free from what is sometimes called "the bull's-eye" effect, as the maximum rays are not concentrated into anywhere near a parallel beam, but are spread over an angle of 20°, and rays equal to twice the mean spherical candle-power of the two lamps are spread over an angle of 40°, which is generally the whole width of the road at a distance equal to twice the height of the post.

Best Means of illuminating Different Classes of Streets.—In order to ascertain the most suitable type of lamp to use for the purpose, when basing calculations on minimum illumination it is necessary to know the candle-power derived from the lamps at an angle of about 20 to 30 degrees below the horizontal, and about 10 degrees on the path side,

and 30 degrees on the road side, of an imaginary line drawn parallel to the kerb; this is, of course, for posts erected on either side of the road, which is the present-day practice. For lamps giving an equal candle-power at all parts of the lower hemisphere, this figure will, of course, be the same as the mean hemispherical candle-power; but for lamps such as arc lamps, gas mantles, various types of Nernst lamps, and special reflector fittings, it must be taken from actual measurements made at the various angles.

As many of you have probably not the opportunity of making these measurements, I submit the following table, No. III., which is based on the average of a large number of measurements made in the street under working conditions.

TABLE III.

showing average mean candle-power of lamps 20° to 30° below horizontal, and 10° one side and 30° the other side of a line drawn parallel to the street.

Electric Lamps.	Watts Consumed per Hour.	Candle Power at Angles Stated.
(1) Flame Type	400	1,300
(2) Open-type Arc	500	500
(3) Enclosed Arc	1,000	1,100
(4) "	600	550
(5) Reason Fitting Incandescent Lamps	200	120
(6) " "	120	70
(7) " "	60	30
(8) Reason Fitting Tantalum Lamps ...	70	110
(9) Nernst Lamps "A" Type	100–120	40
(10) Nernst Lamps "B" Type	50–60	15
Gas Lamps.	**Gas Consumed per Hour.**	**Candle Power at Angles Stated.**
(11) High-pressure Mantles	30 c.f.	515
(12) " "	20 c.f.	215
(13) Intensified Gas, 2 Mantles (City) ...	7·5	130
(14) 2 Low-pressure Gas Mantles ...	7·5	75
(15) 1 Low-pressure Gas Mantle ...	3·75	37

In order to ascertain the gas consumption of the high-pressure mantles, Nos. 11 and 12, and of the intensified mantle, No. 13, I have had to go by the figures in the Gas Journals, in which No. 1 is generally stated as 1,000 c.p., giving 30 candles per cub. ft., and No. 2 as 600 c.p. of the same consumption. The candle-powers given are

the average of a large number of measurements I have made, which agree very closely with measurements made by others. But I would particularly call attention to class 13, which is scheduled under intensified gas, and appears unduly high. In my opinion this is due to the mantles being renewed at more frequent intervals, as it is based on measurements made in Fleet Street, which, it must be borne in mind, is what may be called without prejudice a test case.

It is now comparatively easy to set down the numbers of posts and fittings per mile necessary to obtain the minimum illumination generally provided for various classes of streets, but in order to facilitate this process it is well to have before you a further table, showing the direct illumination derived at various distances from a lamp giving 1 c.p. at that point; with this it is only necessary to find the figure which when multiplied by the various candle-powers gives the required illumination and then by turning to the distance column and multiplying it by two the resulting figure will be the distance separating the posts.

A statement worked out in this way will be found in Table IV. the reference numbers relating to the lamps being the same as in Table III.

TABLE IV.

Distance apart of Lamps of Various Types to give Required Minimum Illumination.

Type of Lamp.	Main Thoroughfares. Min., 0·05 c.p.f.		Side Streets. 0·025 c.p.f.		Suburban Streets. 0·005 c.p.f.	
	Distance apart. Feet.	Posts per 1,000 yds.	Distance apart. Feet.	Posts per 1,000 yds.	Distance apart. Feet.	Posts per 1,000 yds.
1. Electric Flame	300	10	—	—	—	—
2. Open Arc ...	200	15	—	—	—	—
3. Enclosed Arc...	300	10	—	—	—	—
4. " "	200	15	300	10	—	—
5. Reason Fitting	100	30	140	21	300	10
6. " "	70	43	100	30	450	13
7. " "	45	66	65	46	150	20
8. " "	90	33	130	23	290	10
9. Nernst Lamp...	55	54	75	40	180	17
10. " "	—	—	45	67	110	27
Gas Lamps.						
11. High Pressure	200	15	300	10	—	—
12. " "	120	25	180	17	—	—
13. Intensified ...	100	30	140	21	—	—
14. Ordinary... ...	75	40	105	28	240	12
15. "	50	60	75	40	170	17

It must be quite understood that the above table is only approximate, and that it and the following table, of which it forms a factor, are therefore simply for comparative purposes.

From Table IV. it is easy to calculate the quantity of electrical energy and gas consumed for illuminating 1,000 yards of streets, up to the various standards necessary with the illuminants at one's disposal; and if electrical energy be taken at 1½d. per Board of Trade unit, and gas at 2s. per 1,000 cubic feet, a very useful table of comparative costs is arrived at. In order to make this approximately annual cost, I have taken the burning hours at 4,000; the results are given in the following table.

TABLE V.

No. of System.	Main Streets.				Side Streets.				Suburban Streets.			
	Elec. Units.	£	s.	d.	Elec. Units.	£	s.	d.	Elec. Units.	£	s.	d.
1	16,000	100	0	0	—	—			—	—		
2	30,000	187	10	0	—	—			—	—		
3	40,000	250	0	0	—	—			—	—		
4	36,000	225	0	0	24,000	150	0	0	—	—		
5	24,000	150	0	0	16,800	105	5	0	8,000	50	0	0
6	20,640	129	5	0	14,400	90	0	0	6,240	38	11	0
7	15,800	98	15	0	11,000	68	15	0	4,800	30	0	0
8	9,000	56	5	0	6,440	40	5	0	2,800	17	10	0
9	24,000	150	0	0	18,000	112	10	0	7,480	46	15	0
10	—	—			15,000	93	15	0	6,000	37	10	0
	Gas 1,000 c.f.				Gas 1,000 c.f.				Gas 1,000 c.f.			
11	1,800	180	0	0	1,200	120	0	0	—	—		
12	2,000	200	0	0	1,360	136	0	0	—	—		
13	900	90	0	0	630	63	0	0	—	—		
14	1,200	120	0	0	840	84	0	0	360	36	0	0
15	900	90	0	0	600	60	0	0	255	25	10	0

This table may create great surprise in the minds of many, but it is absolute proof of a theory which very few people realise, namely, that the more the light is broken up into small units, the more efficient will be the general illumination; this fact has been appreciated as regards indoor illumination, but it has not been applied to outdoor illumination; before saying any more on this point I will pass on to the next detail—namely, the cost of maintenance of the various types of lamps.

This, again, I have gathered from various sources, but as the interest and sinking fund on mains and services is very rarely charged to the street lighting, I propose to leave out this item for the present; on the other hand, I include interest and sinking fund on all apparatus proper, including the posts. It has been difficult to obtain any reliable information regarding high-pressure gas lamps, but I have included an average of that which I have been able to obtain.

TABLE VI.

giving maintenance charges, including renewals, cleaning, lighting, and extinguishing, interest and sinking fund, but excluding cost of electrical energy and gas. Extended over a period of 4,000 hours.

		£	s.	d.
(1)	Electric Flame Arc (long burning)	9	0	0
(2)	" Open Arc	9	0	0
(3)	" Enclosed Arc	4	10	0
(4)	" "	4	0	0
(5)	" Reason Fitting	1	0	0
(6)	" "	1	0	0
(7)	" "	1	0	0
(8)	" Reason Tantalum Lamps	2	15	0
(9)	" Nernst Lamps	1	2	0
(10)	" "	1	2	0
(11)	Gas High-pressure Mantles	7	0	0
(12)	" "	5	10	0
(13)	" Intensified	2	5	0
(14)	" 2 Low-pressure Mantles	1	15	0
(15)	" 1 Low-pressure Mantle	1	10	0

NOTE.—The maintenance for both gas and electric lamps will of course vary in accordance with local conditions, but the above can be taken as a fair average when bearing in mind that the small c.p. lamps refer more particularly to small towns and the large lamps to larger towns.

If the above costs be added to those in the preceding Table V., we get the results shown in Table VII., which will give the average total cost per annum for all night lighting of 1,000 yards of streets, under the various requirements and conditions of lighting.

TABLE VII.

TOTAL COST PER ANNUM (4,000 HOURS) PER 1,000 YARDS OF STREET.

Electric— MAIN STREETS.

System.	Supply. £	s.	d.		Maintenance. £	s.	d.		Total. £	s.	d.
(1)	100	0	0	...	90	0	0	...	190	0	0
(2)	187	10	0	...	135	0	0	...	322	10	0
(3)	250	0	0	...	45	0	0	...	295	0	0
(4)	225	0	0	...	60	0	0	...	285	0	0
(5)	150	0	0	...	25	0	0	...	175	0	0
(6)	129	5	0	...	43	0	0	...	172	0	0
(7)	98	15	0	...	66	0	0	...	164	15	0
(8)	56	5	0	...	100	15	0	...	157	0	0
(9)	150	0	0	...	59	8	0	...	209	8	0
(10)	—			...	—			...	—		

TABLE VII.—*continued.*

Gas— MAIN STREETS.

System.	Supply. £	s.	d.		Maintenance. £	s.	d.		Total. £	s.	d.
(11)	180	0	0	...	105	0	0	...	285	0	0
(12)	200	0	0	...	137	10	0	...	337	10	0
(13)	90	0	0	...	67	10	0	...	157	10	0
(14)	120	0	0	...	70	0	0	...	190	0	0
(15)	90	0	0	...	90	0	0	...	180	0	0

Electric— SIDE STREETS.

System.	Supply. £	s.	d.		Maintenance. £	s.	d.		Total. £	s.	d.
(1)	—			...	—			...	—		
(2)	—			...	—			...	—		
(3)	—			...	—			...	—		
(4)	150	0	0	...	40	0	0	...	190	0	0
(5)	105	5	0	...	21	0	0	...	126	5	0
(6)	90	0	0	...	30	0	0	...	120	0	0
(7)	68	15	0	...	46	0	0	...	114	15	0
(8)	40	5	0	...	63	0	0	...	103	5	0
(9)	112	10	0	...	44	0	0	...	156	10	0
(10)	93	15	0	...	50	12	0	...	144	7	0

Gas—

System.	Supply. £	s.	d.		Maintenance. £	s.	d.		Total. £	s.	d.
(11)	120	0	0	...	70	0	0	...	190	0	0
(12)	136	0	0	...	93	10	0	...	229	10	0
(13)	63	0	0	...	47	5	0	...	110	5	0
(14)	84	0	0	...	49	0	0	...	133	0	0
(15)	60	0	0	...	60	0	0	...	120	0	0

Electric— SUBURBAN STREETS.

System.	Supply. £	s.	d.		Maintenance. £	s.	d.		Total. £	s.	d.
(1)	—			...	—			...	—		
(2)	—			...	—			...	—		
(3)	—			...	—			...	—		
(4)	—			...	—			...	—		
(5)	50	0	0	...	10	0	0	...	60	0	0
(6)	38	11	0	...	13	0	0	...	51	11	0
(7)	30	0	0	...	20	0	0	...	50	0	0
(8)	17	10	0	...	27	10	0	...	45	0	0
(9)	46	15	0	...	18	14	0	...	65	9	0
(10)	37	10	0	...	29	14	0	...	67	4	0

Gas—

System.	Supply. £	s.	d.		Maintenance. £	s.	d.		Total. £	s.	d.
(11)	—			...	—			...	—		
(12)	—			...	—			...	—		
(13)	—			...	—			...	—		
(14)	36	0	0	...	21	0	0	...	57	0	0
(15)	25	10	0	...	25	10	0	...	51	0	0

The foregoing tables demonstrate several interesting points, the importance of which I consider cannot be over-rated. They are as follows :—

1. The use of large units of light for general street illumination is expensive, and should be avoided where possible.

2. The cost of maintenance is very often as high, if not higher, than the cost of electrical energy or gas; it must be borne in mind that in the foregoing table electrical energy is taken at 1½d. per unit—it is very often less than this for street lighting, in which case the cost of maintenance becomes a still more important factor.

Possible Improvements.—Before concluding, I should like to give my opinion of the directions in which I believe improvements are likely to be made with existing electric lamps and apparatus for the particular purpose under consideration; these are:—

1. Improvements in the methods of connecting and controlling electric lamps.
2. Reduction in maintenance costs.
3. Correct disposition of lamps and choice of suitable fittings, etc.

Improvement No. 1 is probably the one which should be and must be dealt with when street-lighting installations are being originated. It is by far too common a practice to connect street lighting across the ordinary distributors in the same way as gas lamps are connected to the existing gas mains. In the case of gas lamps, nothing could be gained by adding to the usual mains, as it is essential that each lamp should be lighted individually, without any complicated or wasteful ignition apparatus being used. With electric lamps quite another condition of affairs exists. A saving of at least 6s. per post, which sometimes amounts to 15s. per annum, can be made by using a separate network, and if this street-lighting network is laid on a suitably-designed basis—such as that used by Mr. Wilkinson, of Harrogate—a considerable saving results.

Methods of connecting Street Mains.—Mr. Wilkinson has kindly given me particulars of the system of street-lighting mains which he has recommended for Harrogate; briefly described, it consists of laying unarmoured cables in steel tubing situated underneath the flags or paving adjacent to the kerbstones. Not only does this system dispense with the cost of excavating, but also has the advantage that the pipes and mains are in a fairly dry and accessible place, and can be laid without causing street obstruction. For the purpose of comparison I have drawn up Table No. VIII., giving the approximate cost of mains and services for 1,000 yards of street, providing for 38 posts placed on one side of the road only; you will notice that I have given both series and parallel systems of connecting the lamps, for reasons I will describe later.

NOTE.—In the series system it is taken for granted that the street mains are connected to a distributor or feeder at each end of the street. From the above table it will be seen that, provided a suitable system of mains is used, the sinking fund will in no way approach the cost of separate switching, which point, combined with the advantages of

central control, tends to the conclusion, in my mind, that a separate network should be put down where possible.

Choice of Lamps.—It will probably have been noticed that the highly efficient incandescent types of lamps which are now being put on the market, such as tantalum and osmium, are much more suited for low voltage than high; in fact, the high prime cost and reduced lasting powers of these lamps is largely due to the attempts the makers have made (by reducing the sectional area and increasing the lengths of the filaments) to adapt them to the existing pressures of supply undertakings. Now, these lamps, provided their lasting properties are improved, are eminently suited for street lighting, on account of their high efficiency and steady light-giving power.

I have therefore lately been experimenting with these lamps connected in series with most gratifying results, and trust shortly to be able to recommend the supply of these lamps for street-lighting purposes. They will be low voltage (10 to 30), with thick filaments,

TABLE VIII.

System.	Cost per 1,000 Yards.	Interest and Sinking Fund at 6 per Cent.	Interest and Sinking Fund per Post.
	£	£ s. d.	s. d.
Twin lead-covered armoured... ...	300	18 0 0	say 9 6
Single „ series	200	12 0 0	6 3
Wilkinson system parallel	100	6 0 0	3 2
„ „ series	75	4 10 0	2 7
Connecting to existing distributor ...	40	2 8 0	1 3

intended to be run in series throughout the street, controlled at the end of each series by a magnetic relay switch connected to the previous series, in a similar manner to that used for arc lighting by Mr. Robinson, of Hackney, and others. A very simple cut-out designed by myself prevents a fault in any lamp extinguishing the series.

I will now give an example showing the cost of installation, maintenance, and supply of energy for lighting 1,000 yards of street on this principle.

Taking the average side street requiring a minimum illumination of 0·025 c.p. foot, using lamps giving a maximum of 40 c.p. in the required direction, 38 posts and lanterns would be necessary. If each of these is fitted with two osmium lamps giving 10 c.p. each, they will, with Reason reflectors, provide the necessary candle-power.

With a 440-volt distribution, the two lamps in each lantern would be connected in parallel; the posts being connected in series, 11-volt lamps would, therefore, be suitable. If these are giving 10 c.p. each, the filaments would be short and thick and would probably last several thousands of hours.

The diminution of c.p. with the osmium lamp is so small that 2,000

hours' burning per lamp should be satisfactory. The following estimate is therefore probably correct :—

CAPITAL CHARGES.

	£	s.	d.
Mains and services	75	0	0
38 posts erected	57	0	0
38 lanterns and reflectors	45	0	0
Relay switch and cut-outs, etc.	23	0	0
	£200	0	0

RUNNING CHARGES (per 4,000 hours).

	£	s.	d.
Interest and sinking fund on above at 6 p.c.	12	0	0
152 lamps at 3s.	22	16	0
Cleaning, etc., at 3s. per post	5	14	0
4,000 units at 1½d. per unit	25	0	0
Total annual cost	£65	10	0
Total annual cost per post	£1	14	6

These figures show that even when including interest and sinking fund on all materials and mains, street lighting can be carried out at a profit by means of electricity at a price far below the average charge for gas when giving the same result as regards illumination. Moreover, this system of connecting and control is the best method of embodying improvement No. 2, as it permits of further economies, such as reduction of burning hours, dispensing with the lamps or some of them on moonlight nights. The erection of new posts makes it possible to space the lamps at the correct distance for the class of street which is to be lighted and the type of lamp to be used. You will notice I have taken 10-c.p. 11-volt lamps in the example, but it is quite conceivable that, say, 15 or 20 c.p. lamps would result in a further saving if the lamp renewals are to cost 3s. or more, though, of course, the diversity factor would be increased.

In my calculations it is easy to see that I have not favoured electricity in any way. In taking the cost of gas at 2s. per 1,000 cub. ft. I have taken a price which only 12 towns out of 223 are able to charge, all the others being higher; whereas 1½d. per Board of Trade unit is higher than is being charged by a large number of electrical undertakings.

The price at which electrical energy can be supplied at a profit for street-lighting purposes has been so ably dealt with by others that I do not propose to say much on this subject, but would ask you to consider it from a somewhat novel point of view.

As you are aware, the average earning capacity of every kilowatt of plant installed is about £10 per annum. A kilowatt supplied during 4,000 hours per annum represents 4,000 units; thus in order to earn the

same amount per kilowatt on a street-lighting load it would only be necessary to charge 0·6d. per Board of Trade unit. I do not suppose for one moment an electrical undertaking would expect to make more out of their street lighting than out of the average supply, therefore it will be seen that in charging 1½d. per unit I have probably put the figure at more than twice what it should have been in the majority of cases. This makes the comparative cost of the two illuminants even more accentuated in favour of electricity.

In conclusion, I trust that I have been able to prove that we have at disposal in electricity a force which, if properly applied, can be used for lighting streets more efficiently and at less cost to the ratepayers than any other form of illuminant available. It rests with electrical engineers to advance this branch of our business much more rapidly than it has advanced during the last few years. I am not a believer in the proverb that everything comes to those who wait. Street lighting will not come to those electricity undertakings the engineers of which do not use every effort to obtain it. Far too many are prepared to sit still and allow the gas companies to retain this most valuable load and even more valuable advertisement. Those who have studied the matter carefully are aware that in nine cases out of ten the lighting of the streets still remains in the hands of the gas companies, simply on account of the business push and acumen of their managers. Is it surprising that gas companies in many cases retain this branch of the business when many electrical engineers are so disinterested in the matter as not to trouble to find out what can be done?

It is a very common practice to leave the choice of lamps, etc., to the lighting committee. This is not fair either to the committee or the engineer. The latter is paid to advise the committee, and see that they get the most efficient apparatus for the purpose; it is therefore wrong that he should use no effort to prevent his employers being misled by appearances. Engineers have often said to me, "The committee like the appearance of such and such a globe, therefore I have put it in to please them." Would the same engineer have put in a beam engine to drive his generators because his committee like to see the beam move up and down? Yet the effect of lighting the streets badly would ultimately prove a more serious obstacle to the success of that undertaking than even the beam engine. I would, therefore, impress upon you again the importance of not allowing one of the most valuable branches of our business to be absorbed by others, simply because they are more persevering in forcing statements and claims they cannot substantiate before the notice of those who control the lighting of our streets.

Finally, I wish to record my indebtedness to the various gentlemen who have so kindly assisted me from time to time by sending me particulars of the street lighting under their control. Also to Mr. Kent, of Croydon, and Mr. Fairey, of Finchley, for assistance in making photometric measurements in the streets, and finally to Mr. Haydon, of Faraday House, who has done much of the tabulating and similar

work which has been necessary in order to show the various figures of comparison.

DISCUSSION.

The Chairman.

The CHAIRMAN (Mr. S. L. Pearce): Not the least interesting portion of the paper is that dealing with the various methods of measuring illumination. Seeing that all tests are made largely for comparison, I think it preferable to focus the light and measure the normal ray at various distances from the source of illumination. This method eliminates all reference to the angle of the screens, and also disposes of any consideration regarding height of lamps. Direct illumination, of course, means making an adjustment every time a measurement is made at a different angle, but this adds nothing appreciably to the length of time taken; every photometer maker takes this point into consideration in the design of the instrument. With reference to the Manchester curves, the candle-power foot for the normal ray was measured at different distances from one source of illumination, and then the photometer was turned round and similar measurements taken from the second source. Two overlapping curves were thus obtained, and by summing these a third curve was arrived at, which gave the total maximum illumination sent to any point from the two sources of light. I cordially agree with the author that the use of a few large units of light for street illumination does not give the best results, but I am not prepared to go to the limit Mr. Harrison did in the other direction.

Professor Schwartz.

Professor A. SCHWARTZ: I sympathise with the author's evident desire for simplicity, but I am afraid that in endeavouring to attain this simplicity the author has partly disregarded some matters of fundamental importance. In common with most engineers, he has almost totally disregarded questions of colour, steadiness, and suitable intrinsic brilliancy, and the consideration of these is very important. If you recognise that the human eye has been developed under the influence of sunlight, you will agree that that artificial light which most closely approximates in composition to daylight will be the most suitable for seeing by. Daylight is only white about noon, and as the sun sets, more and more of the blue rays are filtered out by the atmosphere and the light becomes more yellowish in character. I am in favour of an artificial light with the same tendencies; some arc lamps which are bluish and Welsbach lamps, which are greenish, are not so visually useful as they might be. Further, on examining the spectrum of daylight with a photometer, about 80 per cent. of the total luminosity will be found to reside in the yellow region. With regard to the question of intrinsic brilliancy, it should be a fundamental rule of proper illumination that all radiants of high intrinsic brilliancy should be kept out of the field of view as far as possible, unless protected with diffusing globes. I consider high-temperature filaments, such as in the tantalum, osmium, and Nernst lamps, particularly when furnished with the author's reflecting device, too trying if not shaded and if mounted on short posts. The author has stated that the process for obtaining contour curves after the manner of Mr. Trotter was so

laborious and intricate that he could not advise any one to undertake it. Stimulated by this remark, I have, in conjunction with my colleague, Mr. C. F. Smith, taken some of the interesting and valuable illumination curves obtained by Mr. Pearce for the Manchester streets, and I have plotted the contours by a simple graphical process, shown in Fig. A. Considering the illumination from two sources, A and B, the 1 candle- Professor Schwartz.

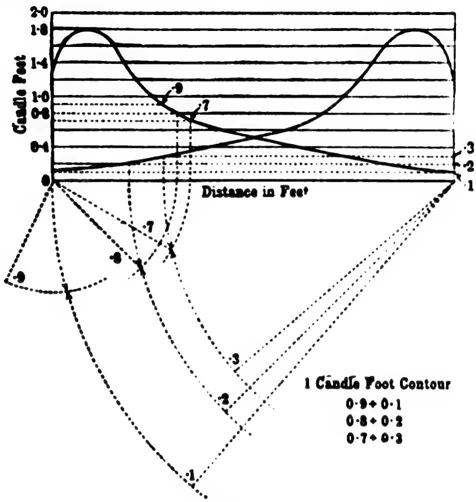

FIG. A.

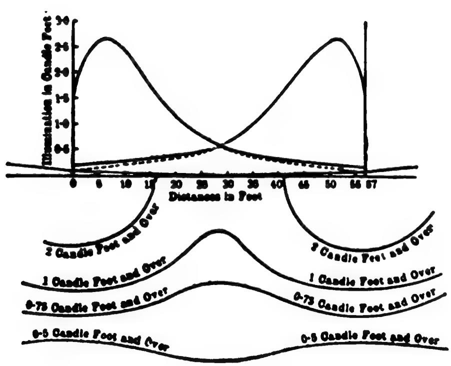

FIG. B.—Curves for Gilbert Arcs.

foot contour could be plotted from the intersection of circles of equal illumination, described about A and B as centres. Figs. B and C show contours obtained in the case of the Gilbert arcs in Albert Square and the intensified gas outside the School of Technology. I do not quite know what the author means by the term diversity factor, but I presume it refers to the rate of change of the illumination, in which

Professor Schwartz.

case it will not be sufficient to know only the maximum and minimum values, as the author claimed. The iris at full aperture has an area of from 15 to 20 times that of its minimum opening, and its rate of accommodation is slow, being several seconds, and it must be borne in mind that the real criterion of visual usefulness is not the illumination, but the product of the illumination and the effective aperture of the iris at the time.

Mr. Sands.

Mr. D. L. SANDS: I see no reason whatever for using a fixed photometer screen, though 45 deg. is probably the best angle for a fixed screen. The author in objecting to the use of a movable screen states

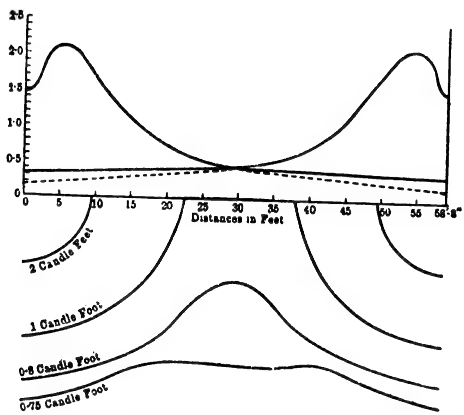

FIG. C.—Curves for Intensified Gas alongside School of Technology.

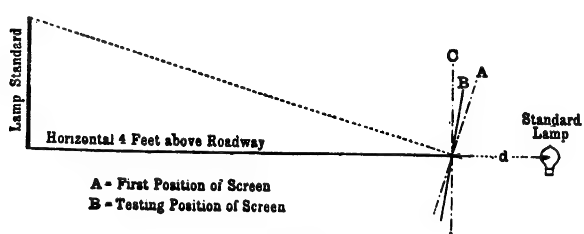

FIG. D.

"that it requires another adjustment every time a measurement is made, thus not only complicating the design of the instrument, but also increasing the time occupied in making the tests." My experience is that with a direct-reading photometer the adjustment objected to by the author can easily be made in five or six seconds, and that this adjustment, besides enabling the operator to obtain the direct illumination from the source of light, insures that the source is in strict alignment with the photometric axis. Fig. D illustrates these points. The disc on being turned from the sighting position A (normal to incident beam) to the testing position B (midway between lines A and C), presents the same

angle of incidence to both light sources, then the value $C P/d^2$ is the direct illumination from the source under test—*i.e.*, illumination on a surface in position A, the value C P being the candle-power of the standard lamp employed. The illumination on a horizontal surface at this point can easily be obtained by multiplying the value $C P/d^2$ by the sine of the angle contained between lines A and C. A great advantage of this arrangement is that the further away from the light source the photometer is placed the more nearly normal does the disc become to the incident beam, whereas in the case of the screen fixed constantly at 45 deg. the incident beam is exactly normal to the disc at a point in the street which is as far distant from the lamp standard as the light source is above the photometer; but if the photometer is moved in either direction from this position the angle of incidence is increased, and consequently the sensitiveness of the instrument is depreciated, especially in the case of low-intensity street lamps. Mr. Sands.

Mr. J. G. NEWBIGGING (Chief Engineer Manchester Corporation Gas Department): I defend the value of the opinion of "the man in the street," whose views on street lighting are quite unbiassed, although treated with contempt by the author. I do not know on what grounds he claims that electrical engineers have less antipathy to the actual measurement of street lighting than gas engineers have. The latter have everything to gain by such a method of comparison, because, on the author's own showing, a so-called 1,000-c.p. arc lamp only gives an actual light of 600 candles, or 40 per cent. less than the nominal power. If photometrical observations were taken of a nominal 1,000-c.p. gas light and a nominal 1,000-c.p. arc light at intervals of, say, 10 minutes over a period of several hours, it would be found that the gas light would give a greater percentage of efficiency than the arc light, and this is the only true basis of comparison on photometrical lines. It is, however, well known that the varying conditions existing in the streets, such as vibration and the state of the atmosphere, render the comparisons on photometrical lines alone not absolutely reliable. There is another point in making a comparison between electric arc lighting and incandescent gas lighting that must not be lost sight of, and that is, in the case of electric arc lighting the whole of the light is reflected downwards by the aid of reflectors, whereas in the case of incandescent gas lighting a portion of the light is allowed to travel upwards. This accounts for the increased illuminating power which has been obtained by Mr. Pearce and others when taking photometrical observations of the two systems of street lighting. It is a moot point whether the reflecting of all the light downwards is advisable, because the sharp line which divides the darkness above the reflector and the light below the reflector creates an oppressive effect on those walking in the street. It is, after all, largely on the general lighting effect by which different methods of street lighting will be judged, and I maintain that if this general effect in the one case is better than in the other it is impossible to prove by photometry that the opposite is the case. According to Mr. A. C. Morton, the chairman of the Streets Committee of the City of London Court of Common Council, since the Mr. Newbigging.

Mr. Newbigging.

replacement of some of the City lighting by incandescent gas they had been getting four times the light for the same money. In comparing the respective prices charged for gas and electricity, the author states that in taking the cost of gas at 2s. per 1,000 cub. ft., he has taken a price at which only 12 towns out of 223 were able to charge, all the others being higher, whereas 1½d. per Board of Trade unit is higher than was being charged by a large number of electrical undertakings. I would like the author to show me the electricity undertaking in existence that is able to make the same percentage of profit, or, in fact, any profit at all, on their capital outlay, by charging an average all-round price of 1½d. per unit, as the gas undertakings do who charge 2s. per 1,000 cub. ft. Making a comparison between the gas and electric undertakings of Manchester, I find the gas undertaking had last year a surplus profit twelve-and-a-half times greater than the electrical, taking the respective capital outlay in both cases into consideration, so that to make a fair comparison of the cost of street lighting on the two systems it would be necessary for the electrical undertaking to increase largely their charge of 2d. per unit for street lighting. The argument brought forward by the electricians that as the street-lighting customer is a heavy-load customer they are able to supply him at a less cost applies equally to the gas undertaking. I am of the opinion that the question of the respective values of gas and electricity for street lighting, both from the point of view of effectiveness and cost, can only be settled by each department in a town or city having allotted to it an equal area, say a street or square, and each undertaking the lighting on a basis to be agreed upon, the total cost in each case of capital outlay and maintenance carefully noted, and the consumption of gas and current properly registered, photometrical observations of the lights being taken on equal lines. I am convinced that incandescent gas lighting has nothing to fear, and will in the future still more firmly establish itself as the best and cheapest method of lighting the streets.

Mr. Maxwell.

Mr. H. B. Maxwell (*communicated*): The author bases his whole paper on the supposition that the proper thing for street lighting is a small source of light placed at short distances with a certain standard of illumination at the darkest point. This would be correct if the ordinary ratepayer wished to read "Bradshaw" in the street, and at the particular point where the illumination was lowest. This, however, is not what is required, but that any one walking or driving down a street may see obstructions, or other objects, at the greatest distance. My experience is that objects on the street at some distance from the observer are not distinct, and at certain positions relative to the lights, are quite invisible with such a system of lighting as incandescent gas, or the Reason reflector fitting. The latter is undoubtedly effective in giving a greater light than with incandescent gas, at a slightly lower cost, but surely we should aspire to something vastly superior to that (I am of course referring to ordinary lighting, and not to costly advertisements like the Kingsway and Aldwych lighting), and I am satisfied that really good results can only be obtained with the more efficient arc lamp.

I should very much like to know where the author got his figures for the maintenance of arc lamps. They must be purely an estimate, and a very poor one at that. He states in Table VII. that the cost of maintaining 500-watt arc lamps, including carbons, wages, repairs and interest and sinking fund, is £135 for fifteen lamps, or £9 per lamp per annum. For the past two years I have been maintaining 300 arc lamps taking 625 watts each at a cost of £4 per lamp per annum. This price was obtained with six men working altogether, four ladders and with 26-foot poles, which is exceptionally high. I should be very much pleased to maintain any number of 500-watt arcs on lower poles, with more modern arrangements, at £4 10s. per lamp per annum, or including current at £13, as compared with £21 10s. per lamp per annum estimated by Mr. Harrison. I should, on the other hand, be very sorry to undertake arc street lighting with enclosed lamps at double the figures given in Table VII. for maintenance. The author has taken such great care to give only actual figures as to candle-power, etc., that it is a pity the accuracy, and hence the value, of the paper has been spoilt by these estimates. I was pleased to see that he is able to state from actual measurement that the present lighting in Fleet Street is inferior even to the old antiquated arc lanterns, for that was certainly my impression when I recently saw it. I should like to say in conclusion that in spite of mistakes it is the most interesting and instructive paper I have read, especially that portion dealing with the photometric measurements of lamps. Mr. Maxwell.

Mr. A. P. Trotter (*communicated*): The utmost simplicity is desirable in giving names to physical units. We speak of "watts per candle" or "candles per watt." A candle is no good unless it is emitting light at the rate of a candle-power; hence a "candle-foot" is better than a "candle-power-foot." I admit that the "candle-foot" is open to objection, for it is not, like all other compound units, the product of two others, but it is the quotient, and is more strictly expressed as a "candle per square foot." Many years ago the editor of *Industries* criticised the "candle-foot," and suggested, on the lines of the "mho," that it should be called a "candle-toof-toof." A "candle per square foot" is rather misleading, for the square comes in arithmetically, and not as an area. I prefer the "candle-at-a-foot." The expression is clear but uncouth. In writing on photometry it need not be used more than once, and may then be attended to as c/f^2. The dimensions of the International "lux," of which 12·2 go to a candle-foot, are much more convenient. Mr. Trotter.

There are two reasons why illumination should generally be measured on a horizontal surface, in cases of street lighting. An inclined surface cannot receive light equally from several sources. In some cases so many lights are concerned that it is difficult to get near the photometer without screening it from one or more lamps. In comparing the illumination of important public places, or large railway stations, no useful measurement can be made without taking into account the effect of many lamps. It is very desirable that the illumination of a well-lighted place such as a railway station should be

Mr. Trotter. simply expressed, at least as a minimum, if not more precisely. Then tenders could be invited to a specification, and electrical or gas engineers should be able to estimate, and the result could be tested, not perhaps as accurately as the horse-power of a steam engine, but as closely as the coal consumption. Another reason for the horizontal screen, and the one given in my paper,* is that though such illumination must not be the only consideration of outdoor lighting, a fairly uniform illumination of the ground is the most difficult to secure. If a satisfactory minimum is produced, the rest of the lighting may be left to take care of itself. I do not admit that the difficulty of measuring feeble illumination is a reason for not using a horizontal screen. With a good photometer, measurements down to 0·005 c/f^2 are possible, and 0·01 c/f^2 is easy.

It is true that there are laborious and somewhat intricate parts in my paper of 1892, but I put down all that seemed worth recording in the hope that some of it would be useful in the future. The plotting of theoretical contour curves, so far from being tedious, is an interesting amusement requiring no mental work. I drew on sheets of tracing paper a number of circles having radii representing contours in c/f^2 from one source of light. Tables are given in the paper, from which these radii may be taken. I laid two or three or more such sheets one over the other, marked the intersections, as Professor Schwartz has done, and joined the intersections by curves. The same sheets will do for any desired arrangement of lamps, and may be used over and over again, the resultant curves being drawn on a sheet laid over all.

Mr. Harrison. Mr. H. T. HARRISON (*in reply*): In reply to Mr. Maxwell's remarks (*communicated*), I am sorry he was unable to be present, as in that case I should have asked him in what way my paper is based on the "supposition that the proper thing for street lighting is a small source of light placed at short distances, with a certain standard of illumination in the darkest part." I did take for granted that, provided certain standards of minimum illumination in the darkest parts were considered sufficient, certain numbers of posts per 1,000 yards would be required, depending on the candle-power of the lamps erected on each post, and proceeded to work out the annual costs of the various systems accordingly. Mr. Maxwell also appears to be under the false impression that I based this minimum standard of illumination on the possibility of reading "Bradshaw"; this is an absolute misstatement, as the only time I mentioned that railway guide was when considering the practical value of illumination, when I referred to it as a usual test. If Mr. Maxwell was in the habit of reading literature on illumination, he would continually come across this rough test, for it is not so foolish as he appears to think. A certain degree of illumination is necessary before anybody with average eyesight can read printed matter, therefore it was necessary to choose some particular book or paper which was always printed in the same size type, on the same quality of paper, and which could not be read by the context. This was no doubt the

* *Minutes of Proc. of Inst. of Civil Engineers*, vol. cx., 1892, p. 69.

reason why Mr. Trotter chose the "Bradshaw" for this purpose in 1892, and why many others have chosen it since. It must be obvious to Mr. Maxwell that if the degree of illumination is sufficient to read "Bradshaw," it will be ample for the other purposes he mentions, which have all been referred to in my paper. Mr. Harrison.

I wish Mr. Maxwell had given us his opinion as to the degree of illumination "we should aspire to," as that is the point I wish to settle; and that he would also bear in mind that that degree of illumination does not depend on what lamps are used—either gas, arc lamps, or Reason fittings—but on the distance at which they are placed. He goes on to say that he is satisfied that really good results can only be obtained with the more efficient arc lamps, by which I conclude he means the lamps used in Partick. I have no doubt that the lighting of the main streets in Partick, where the lamps are placed 180 ft. apart, is excellent, and that it is fairly good where they are placed 240 ft. apart; in the side streets it is also good at 300 ft. apart, but at 540 ft. the darkness between the posts must be very noticeable, and the difference between the maximum and minimum illumination (or diversity factor, as I prefer to call it) in the last two cases must be very great. The point is—could the lighting of the side streets have been carried out equally efficiently and more economically by other means? I venture to say it could; for instance, to light 1,000 yards of side streets Mr. Maxwell uses ten 625-watt open-type arc lamps, thus producing a minimum illumination of 0·025-c.p. ft.; the cost of maintenance he puts at £4 per post (but does not state if this includes interest and sinking fund), thus the cost per 1,000 yards at 1½d. per unit works out as follows:—

$$\textit{Electrical Energy} = \frac{625 \times 10 \times 4{,}000 \times 1\cdot5}{240} = £156\ 5s.$$

$$\textit{Maintenance} = £4 \times 10 = \underline{40\ 0s.}$$

$$\text{Total} \quad \ldots \quad \ldots \quad \ldots \quad \underline{£196\ 5s.}$$

By referring to Table VII., under Side Streets (the minimum illumination of which is only 4 per cent. lower than that in the above example), it will be found that any of the systems exemplified, except No. 12, would have been less costly and the diversity factor would have been reduced. Mr. Maxwell would like to know where I obtained the figures for maintenance of arc lamps, as he thinks they must be purely an estimate, and, as they do not agree with the figures he gets at Partick, he considers they spoil my paper. I was under the impression that I had made it quite clear that the figures in my paper are based, where possible, on averages taken from a large number of undertakings, and the fact that these figures relating to maintenance are much nearer the average than those obtained at Partick, is borne out by Mr. Pearce's and Mr. Robinson's estimates.* I would also like to point out to Mr. Maxwell that low cost of maintenance of open-type arc lamps does

* *Electrician*, vol. lvi., 1905, p. 4.

Mr. Harrison.

not always pay, as it often means using inferior carbons, careless adjustment, and dirty globes, which will reduce the light-giving power of an arc lamp by 50 per cent. For instance, Mr. Simmance's prolonged tests in the streets of Portobello (Edinburgh), which have just been published, show that the 500-watt arc lamps at that place give an average *maximum* of 320 c.p.; this can only be due to the causes above stated. I am surprised that Mr. Maxwell would prefer to maintain open-type arc lamps requiring carboning every 32 hours for a less sum than enclosed lamps, requiring carboning every 100 hours, especially as the latter contain less than half the mechanism of the former.

In reply to Mr. Trotter's remarks (*communicated*), as regards the names given to units, I must point out that I took these as I found them. I have avoided using the "lux," not because I do not realise that it is an excellent unit, but because it has not come into general use. The two reasons which Mr. Trotter gives for using a photometer with a horizontal screen are both good, but, in my opinion, not good enough to overcome the incidental disadvantages. Mr. Trotter appears to have overlooked the fact that I was considering the illumination of streets, and not of public places or large railway stations. Even if I had been considering the latter, I doubt whether horizontal illumination is as important as vertical; for instance, many of us must have come across instances where the platform of a railway station was excellently illuminated, but it was impossible to read the time tables on the walls. This is, therefore, a good example of my point that the illumination of vertical surfaces is often as important as that of horizontal surfaces. Moreover, it is a great question whether the effects of many lamps fixed in all directions should be added together in order to ascertain the illumination resulting; take, for instance, the simple example of two lamps in a street, the illumination on the faces of two pedestrians meeting between these lamps is only equal to the illumination derived from one lamp; but even the value of that illumination would, in the majority of cases, be more than the combined result derived from both lamps on a horizontal screen, owing to the average height and distance apart that most street lamps are placed; therefore, for the purpose of comparing street lamps, illumination on screens at an angle of 45 deg., representing approximately the average between horizontal and vertical illumination, will probably be found the best gauge of efficiency. Mr. Trotter is quite correct in stating that a fairly uniform illumination of the ground is the most difficult to secure. It is also the most difficult to measure. For instance, in his paper, which he refers to, he had to admit that in ordinary streets "the illumination is so very feeble that exact measurement is very difficult"; but I would remind him that if he had been using a screen at the angle I suggest, instead of a horizontal screen, the minimum illumination on the measuring screen would have been six times as great, thus reducing the difficulty of making the measurement.

In reply to the Chairman's remarks, I may point out that the method of adding the illumination derived from two sources together leads to error if the measurements are those of direct illumination taken between

Mr. Harrison.

those sources of light, as no person can see both sides of an opaque object, and, therefore, they benefit by the illumination from one source only. I am glad that the Chairman has come to the conclusion demonstrated by the figures given in the paper, namely, that a few large units of light do not give the best results. As regards the limits to which the multiplication of small units of light should be carried, I consider this is a question of cost. I am glad that Professor Schwartz sympathises with my desire for simplicity, but I see no signs of a similar desire on his part, or he would not lay so much stress on the question of colour or other æsthetic considerations, of which the public are by far the best judges. The contour curves plotted by Professor Schwartz and his method of arriving at them are interesting, but I have long ago come to the conclusion that public lighting authorities are only irritated by the sight of contour curves, and prefer comparisons in figures. The term "diversity factor" means the ratio the maximum illumination at the brightest point of measurement bears to the minimum illumination measured in the darkest part. The assumption that it refers to a rate of change necessitates a time factor, which is unnecessary. Moreover, Professor Schwartz must bear in mind that the iris of the eye does not in any way affect the degree of illumination, but only the value of it to the individual.

Mr. Sands' statement that the adjustment of the angle in a flicker head of the Simmance-Abady type takes only five or six seconds does not agree with my experience. I have used this instrument for the last two years, and made thousands of measurements with it. It is true that the time taken is very short, provided there is enough light to see the reading on the sector, but, as this is rarely the case when making measurements in side streets, much time is wasted in striking matches, etc.

I am very much pleased that Mr. Newbigging was able to be present, as he has confirmed my statement that gas engineers have an antipathy for street photometry by saying that it is impossible to prove anything by photometry, and that he prefers to fall back on the "man in the street." I may point out that I have stated in my paper that I place a considerable value on the opinion of the public as to street lighting, but not on that of any individual, as the individual is called upon to judge on a subject which he knows little about, and is often misled by appearances. Mr. Newbigging's reference to Mr. Morton's statements concerning the City is unfortunate, as up to the present nobody has been able to find half the increase of light promised when the sample lamps now running in the City were erected, even though the newest thing in gas lamps has displaced nearly the oldest type of electric lamps.

ORIGINAL COMMUNICATION.

ON THE TESTING OF CAST-IRON AND OTHER MATERIALS BY THE EWING PERMEABILITY BRIDGE.

Being a Report on Research Work carried out at the National Physical Laboratory.

By ALBERT CAMPBELL, B.A., Associate Member.

The investigation here described was undertaken with a view to determining a suitable method of testing bars of widely different magnetic properties by means of a Ewing Permeability Bridge. The research was carried out in the National Physical Laboratory, at the desire of the Director, who has taken constant interest in the progress of the experiments. It was felt that the magnetic testing of cast iron was of considerable practical importance, and also that in connection with the metallurgical work of the Laboratory, magnetic tests on rods of various alloys were sometimes required. The bridge, as Professor Ewing has pointed out, was intended for the comparison of bars of somewhat similar quality, and has been used with success for such comparisons in some of the experiments detailed below. Professor Ewing informs us that the soft-iron standard supplied with the instrument is only suitable for the usual work of testing iron for dynamos, magnets, etc. (of nearly carbonless steel or forged iron). It was necessary, therefore, to provide and calibrate a series of standards near in magnetic quality to the cast-iron and other materials to be tested. The general scheme of experimenting was as follows :—A number of standard test pieces were prepared from materials covering a range of magnetic quality as wide as possible ; their magnetic curves were determined by Ewing's small yoke method, and finally they were compared in various ways by the permeability bridge. For the sake of clearness in what follows, I shall say a few words on the usual working of these methods, referring the reader for further details to Professor Ewing's book "Magnetic Induction in Iron and other Metals" (3rd edition).

In the Small Yoke Method the two similar bars have a magnetising coil and a secondary coil slipped over each, and are then united to form a closed magnetic circuit by two small yokes consisting of blocks of iron clamped to the bars. Two sets of ballistic readings are taken with

this circuit: (1) with a clear length of rod equal to 4π centimetres, and (2) with the clear length reduced to 2π centimetres. If H′ be the value of $\frac{4\pi\ C_1N_1}{l}$ in case (1) and H″ be its value in case (2), Professor Ewing has shown that the correction for the yoke reluctance (to be subtracted from H′) is equal to H″–H′. The correction is most easily applied by drawing H′–B and H″–B curves.

Materials of Standard Test Pieces.—The materials used comprised the following:—Soft iron, mild steel, tool steel, cast iron, and one of Heusler's alloys. Of these, the soft iron was the pair of standard rods supplied with the instrument; the cast iron was obtained from several different foundries; whilst the specimens of Heusler's alloy were made in the metallurgical department by Mr. Longmuir.* The last-named alloy consisted of copper, manganese, and aluminium in the proportions roughly of 62:30:8; in making it we aimed at poor magnetic qualities.

As it was found that the permeability curves obtained for bars of the above materials did not form a sufficiently complete series, the following method of filling in the gaps was tried, and proved quite successful. In addition to bars of the standard dimensions, pairs of *tubes* were constructed of the same outside diameter as the bars and of various sizes of bore. Seamless steel tube was found very convenient for some of the sizes. The two heaviest pairs of tubes, however, had to be bored out of the solid. It was also found possible to adjust the cross-sections of the tubes by filing a flat all along the length. Two pairs of the tubes were treated in this way, and, when care was taken in placing them in the clamps, no abnormality was noticed in their behaviour. All the tubes were tested in the same way as the bars, the *apparent permeabilities* corresponding to the standard cross-section being determined. Thus the tubes afforded a series of what might be called "diluted" permeabilities. [What I call the "apparent" flux density B_1 is the total flux divided by the sectional area of a bar of normal diameter.]

Tests by the Small Yoke Method.—The separate bars or tubes in each pair were chosen to match each other as well as possible, and for this purpose they were compared for equality in the bridge. In several cases the agreement was practically exact up to H=100, but for some of the materials I had to be content with pairs which differed at some points of their curves by 3 to 4 per cent. in H (for the same B). After this process of matching, each pair was tested by Ewing's small yoke method. When the bars do not differ much, it may be assumed that this method will tend to strike the average value for the pair. The curves had a small correction applied on account of the area of the secondary winding being considerably greater than the cross-section of the bar. (Even at H=100 the correction applied to B is only about 40.)

Tests on Rings.—In order as far as possible to corroborate the results obtained for the rods and tubes with the small yokes, a number of tests

* Heusler's manganese alloys are composed of metals which by themselves do not show magnetic properties, and yet some of the alloys are as magnetic as cast iron.

were made by the ordinary ballistic method upon rings of some of the materials. As it is a very difficult matter to ensure that rings and rods shall be identical in magnetic quality, the results of two sets of these tests seem of sufficient interest to be given in detail.

Set 1. *Cast Iron.*—A bar was cast of diameter 3 cm. and length 50 cm., and in the same box with it there was cast at the same time a ring of about 12 cm. mean diameter. This ring was turned down to suitable thickness for the ballistic tests (the cross-section being about 1 sq. cm.), and from the rod were turned two bars for the yoke method (about

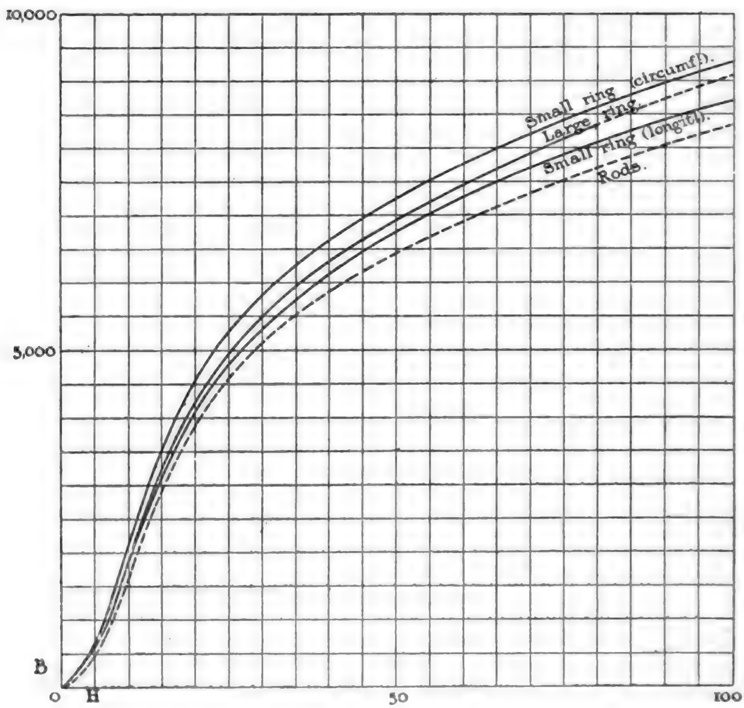

FIG. 1.—Cast-iron Rods and Rings cast together.

9 mm. diameter), and two small rings of 2·4 cm. mean diameter, one of them being cut longitudinally and the other circumferentially from the large bar. These were all tested without annealing, and the results are shown in the curves of Fig. 1. It will be noticed that the H–B curve for the large ring lies between those for the two small ones, while, as would be expected, the ring cut longitudinally shows fair agreement with the two rods. The general agreement here appears to give a good amount of support to the accuracy of the small yoke method.

Set 2. *Mild Steel.*—Very small rings were obtained by cutting short pieces off the mild steel tubes. To give an idea of their smallness

Fig. 2 shows end views of two of them drawn to full size, their walls being about 0·6 and 0·9 mm. thick respectively. Each ring was insulated with silk and wound with 50 turns of fine insulated wire to form the secondary winding. As the inside diameter was very small, being only

FIG. 2.—Small Rings (full size).

7 or 8 mm., very little space was left for the winding to carry the magnetising current. It was found by experiment, however, that a sufficiently uniform H could be obtained by making the primary winding in the form of a sheaf of eight or ten insulated wires quite

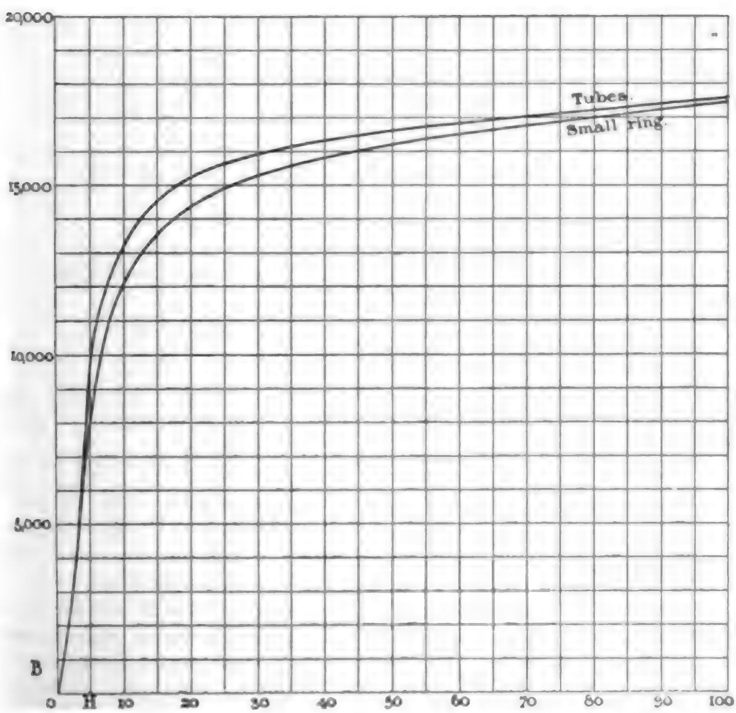

FIG. 3.—Small Ring and Tubes annealed together.

filling the inside of the ring, and straight for about 5 cm. on either side. The distribution of the return paths of these wires appeared to be almost immaterial to the result. By making the ballistic tests very quickly, it was found possible to run the current density in this primary

winding as high as 2,500 amperes per sq. cm. (15,000 amperes per sq. inch) without undue heating, and thus values of H as high as 100 were attained. Two sets of results are shown in Figs. 3 and 4; in these the curves for the tubes show the *real* (not "apparent") values of B calculated for the actual section of the iron. In the first set (Fig. 3) the ring and tubes had been annealed together (at 800° C.), while in the second (Fig. 4) the material was in the condition in which it was received from the makers.

The agreement here shown between the curves for the rings and the tubes (particularly for those annealed together) seems almost as close as could be expected, and hence forms additional evidence in favour of the small yoke method.

Diagram of Standard Curves.—In Table I. are given particulars of a number of standard pieces used.

TABLE I.

Standards.	Description.
a ...	Soft Iron Rods.
b, d, e, g, h ...	Mild Steel Tubes.
c and f ...	Mild Steel Tubes (with filed flats).
i ...	Heusler's Alloy.
m ...	Tool Steel Rods
n ...	" " " (annealed).
p ...	Cast Iron Rods (annealed).
q ...	" " "
r ...	Cast Iron Tubes (bored).

For each pair of these standard pieces tests by the small yoke method gave two curves, viz. (1) the H'–B_1 curve, in which H' is the apparent value of the magnetizing field $\left(\frac{4\pi\ C_1N_1}{10l}\right)$ observed for the full length of the rods not corrected for the yokes, and B_1 is the apparent flux-density, assuming the cross-section of the bar to be of standard size; (2) the H-B_1 curve, where H has the corrected value found in the usual manner by testing the rods also at half length.

The H–B_1 curves for a series of the standard pieces are shown in Fig. 5, each curve having been determined by the small yoke method, *i.e.*, by exactly the same procedure as that used for standardising the soft iron bars (*a*) supplied with the bridge by the makers. It will be noticed that the use of tubes makes it easy to construct a series of standards ranging from very good to very poor magnetic quality. All the curves from *a* to *h* run in a very similar manner. In striking contrast to these is the curve *q*, which is for annealed cast-iron rod (also by the small yoke method). To each of these curves there corresponds an H^1–B_1 curve. This second series of curves is wanted for the method of crossing points described below, but for clearness I

have omitted it from Fig. 5. After their curves had been determined by the small yoke method, some of the standard bars were then compared with one another (by the ordinary method) in the permeability bridge. Two examples of this intercomparison will be sufficient to indicate the general nature of the results obtained ; these are shown in Fig. 6. In this figure the curves *d*, *g* and *h* are the H–B_1 curves for three of the tube standards, whilst the dotted curves g_1 and g_2 show the apparent curves obtained for tube *g* by testing it in the bridge against tubes *d* and *h* respectively, and using the H–B_1 curves already drawn

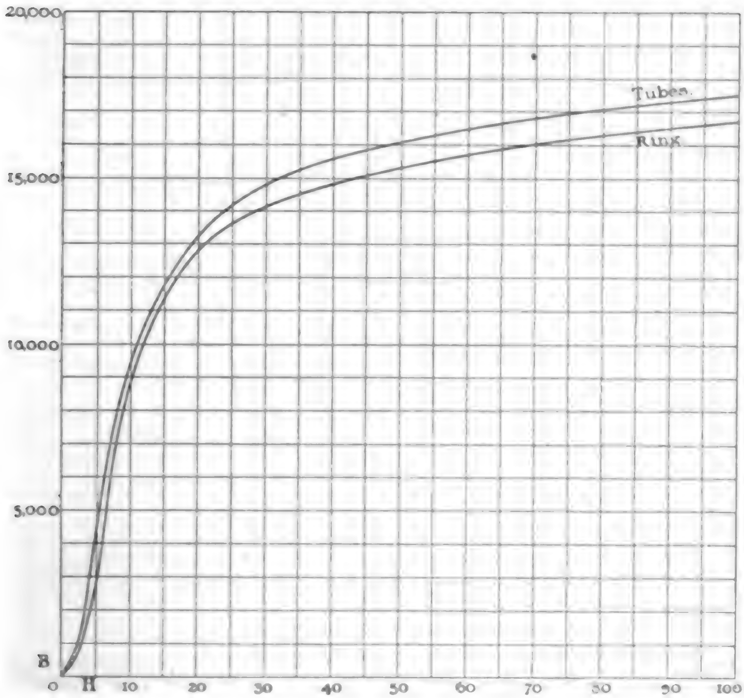

FIG. 4.—Small Ring and Tubes.

for *d* and *h*. It will be noticed that both of these dotted curves are considerably in error from the true curve *g*, the instrument showing a tendency to bring the curve of the test piece too near that of the standard in each case. Similar results were found with solid rods. It is quite clear, therefore, that samples with curves as far apart as *d*, *g* and *h* cannot be successfully compared with one another by the ordinary use of the bridge.

Method of Crossing Points.—The difficulty can be surmounted to a great extent, however, by using the bridge mainly for testing exact magnetic equality, in other words to determine the respective points at which the H^1–B_1 curve of the test piece crosses each of the standard

H^1–B_1 curves. By arranging that the curves shall not cut one another too obliquely, it is easy to determine these crossing points with good accuracy. The practical procedure is as follows: The bridge is set with equal numbers of turns (say 200 for each bar), the test piece and the lowest standard are placed in the clamps, and after demagnetising if necessary, the magnetising current constantly commutated is

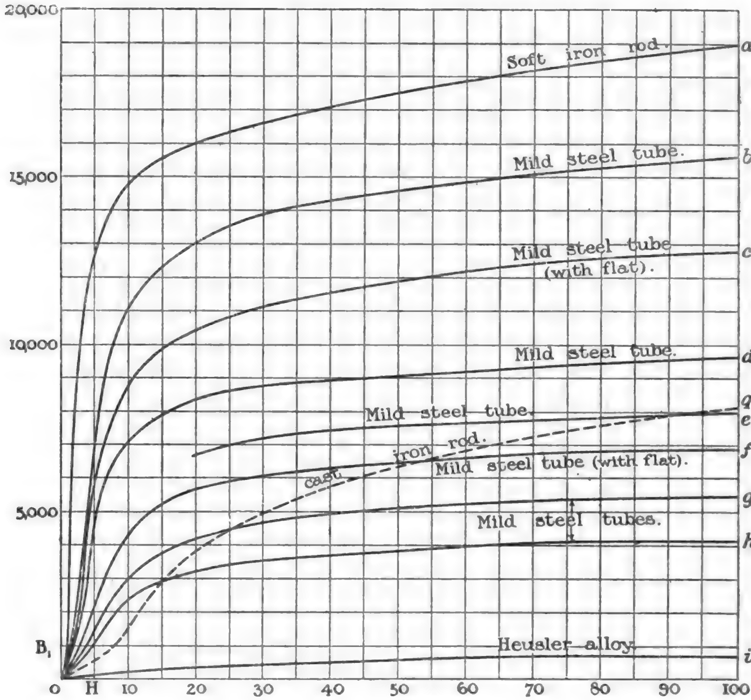

Fig. 5.—Curves of Standards.

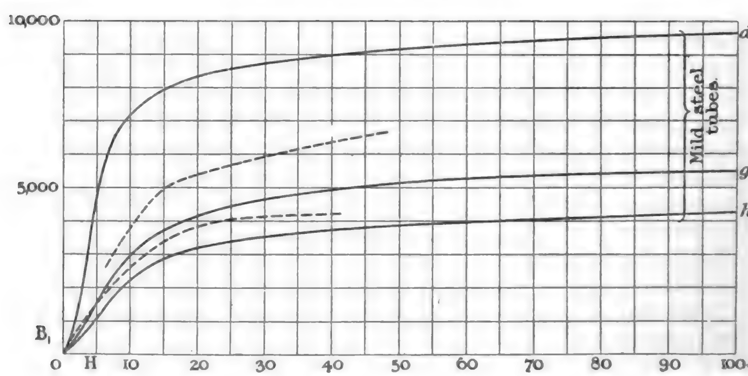

Fig. 6.

gradually raised from a lower value, until an exact balance is obtained. The value of the current for which this occurs gives the H^1 for the first crossing point; by replacing the first standard by the next higher one, and continually raising the current, another point is found, and so on until a sufficient number of points is obtained. When the standards are suitably selected it will usually be found that no more than two or three crossing points are required to give, with sufficient accuracy, the part of the unknown curve that is of importance in practice. The intermediate curves of the series shown in Fig. 5 cover a range suitable for testing various kinds of cast iron. It will be noticed that the crossing points thus found are only points on the curve uncorrected for the reluctance of the yokes and joints. To

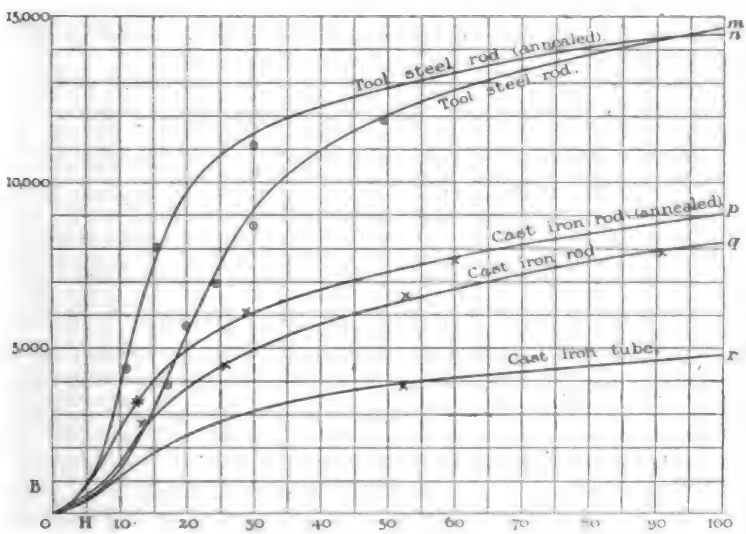

FIG. 7.—Tests by Crossing Points.

obtain the corresponding points on the $H-B_1$ curve it is necessary to know the value of H^1-H. To find this we have no choice but to assume this correction to be the same in the bridge as it is in the small yokes. Again, since at a "crossing point" an exact magnetic balance is obtained, we may reasonably assume the correction (H^1-H) to be the same for the tested bar as for the standard. From the two sets of curves (1) and (2) already mentioned (H^1-H) is known for all the standards, and thus the corrections might be applied. But I have found that the following easier method gives somewhat better agreement with the experimental results. The values of (H^1-H) corresponding to $B_1 = 1,000$, $2,000$, $3,000$, and so on, were tabulated for a variety of different rods and tubes, and an average struck for each value of B_1; the mean values of (H^1-H) thus obtained were used as the corrections in what follows.

In order to test the accuracy of the Method of Crossing Points, several pairs of cast-iron and tool-steel rods and tubes (both with and without annealing) were tested by the small yoke method and their curves drawn. When the crossing points were observed, nearly all of them were found to be in very fair agreement with these curves. For example, in Fig. 7 the curves *p*, *q* and *r* were obtained for cast-iron rods and tubes by the small yoke method, while the small crosses (x x x) show crossing points found independently by testing the same specimens against each of the standard tubes *e*, *f*, *g* and *h*. The curves *m* and *n* were similarly found for tool-steel rods (without and with annealing respectively), and the small circles (⊙ ⊙ ⊙) show crossing points with the standards. For the last two curves, *m* and *n*, the crossing points at $H = 30$ are considerably off the line. The discrepancy does not seem to be due to errors of observation, for the tests when repeated showed the same results.

The cast-iron and tool-steel pieces of Fig. 7 are also useful as additions to the series of available standards, and in some instances one of the standards may be similar enough to the tested piece to allow of the bridge being used in the ordinary way, *but in all cases the H^1–B_1 curves of the standards should be used* instead of the corrected H-B_1 curves which are commonly employed. It may be of interest to mention that the various materials compared in the bridge were very different among themselves in the matter of Time Lag of Magnetisation. It is well-known, for example, that soft iron and mild steel show this effect strongly.* In many of the comparisons the difference of time lag showed itself very clearly by causing the needle of the bridge magnetometer to give a violent throw and then settle down to a steady position. In all the experiments this initial throw was disregarded,† and the balance was obtained by reducing to zero the steady displacement. It seems quite possible that the large differences in magnetic lag may account for some of the crossing points not lying quite on the curves obtained with the ballistic galvanometer (whose complete period was about 8·5 seconds).

The results given in this paper are only a part of a larger series actually obtained; tests were made on about 100 pieces in all. Most of these test pieces were made under the superintendence of Mr. Jakeman, to whom I would here express my best thanks. My thanks are also due to Dr. Carpenter and Mr. Longmuir for their kind help in the preparation and annealing of some of the specimens.

* For a recent research on the subject, see R. Jouast, *Bulletin de la Société Internationale des Electriciens*, ser. 2, vol. iv., No. 40 (1904).

† The importance of working in this manner was clearly pointed out by Professor Ewing in his original description of the instrument.

// JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 36. | 1906. | NO. 177.

Proceedings of the Four Hundred and Thirty-fourth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, January 25, 1906—Mr. JOHN GAVEY, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on January 11, 1906, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members—

Arthur J. Hodgson. | John Gray Scott.
Philip J. S. Tiddeman.

From the class of Associates to that of Members—

Frank Hope-Jones.

From the class of Associates to that of Associate Members—

Edward A. Shaw.

From the class of Students to that of Associate Members—

Sidney B. Haslam. | Thos. B. L. Newstead.
Owen L. Ilbert. | Edgar P. Perkins.

Messrs. A. E. Levin and W. H. Wraith were appointed scrutineers

of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

As Members.

James Mark Barr.
Lieut. Frederick George Loring, R.N.

As Associate Members.

Percy Albert Blake.
Robert Bucknal Bowker.
Herbert Charles Gray.
John Aitken Hoffe.
George Wray Hopkinson.
Thomas Braithwaite Howell.
George William Clarkson Kaye.
Ernest Hugo Leonardt.
Charles George Henry Lewis.
William Duncan Macgregor.
Norman Mathias.
Charles Powis Medley.
James King Murray.
Ernest Arthur Norris.
Joseph Anthony Rivê.
Robert Rowland.
Charles Joyce Russell.
William Thomas Stewart.
Grey Thorne-George.
Hermann Paul Wangemann-Bock.
Archibald Henry M. Ward.
John William Warr.
James Edward Williams.
John Harcourt Williams.
Thomas Wilson.

As Associates.

Frederick William Hartmann.
George Johnson.

As Students.

Herbert Bamford.
Geoffrey Bartholomew.
Herbert A. Bathurst.
Samuel Ernest Roland Beecroft.
Reginald Claude Bowhay.
Robert Stanley Brown.
Frank Buggs.
Charles Albert Butcher.
Alfred John Burford Cornwall.
Louis Gabriel Dalais.
John Darwen.
William James Davis.
George Seward Dearling.
Arthur Douglas.
V. E. Faning.
William Ford.
George Freeman.
Cyril Charles Garland.
D. C. Garner-Richards.
Arthur Granville Gordon.
Ernest O'Donnell Grover.
Peter Harris.
Alfred Gordon Herring.
Lewis William Hipwell.
Wildsmith Henry Janson Holloway.
E. C. Laughton.
Louis Francis Raphael Lewin.
Charles Robert Lodge.
Robert Seton Logan.
John Joseph McKenna.
John Alexander M'Keown.
John Leeson Moffet.
Lancelot Derrick Morphew.
Frank Murphy.
Chalmers Nicol.
Charles Esmond Nightingale.
George Herbert Nott.
S. O'Hara.
William Robert Poole.
Roland John Prankerd.
Cecil H. Reid.
Sam Reid.
Richard James Rooney.
Cyril Hunter Ryley.
Harold Robert Scarlett.
Henry Smith Scott.
Robert Acheson Sheldon.
Kenneth L. Shoobridge.
William Duff Stewart.
Frank Woollaston Timmis.
Archibald Henry Tongue.
S. R. D. Tyssen.
Edward Warnant.
Arthur George Warren.
Ernest Ansley Watson.
Owen John Williams.
John Wilson.

Donations to the *Library* were announced as having been received since the last meeting from the American Institute of Electrical Engineers, Dr. H. Borns, F. B. Crocker, The Electrician Printing and Publishing Co., The Engineering Standards Committee, Gauthier-Villars, Dr. A. E. Kennelly, J. E. Kingsbury, The New York and Ohio Co., R. Oldenbourg, The Patent Office, J. F. Simmance, G. Thomas-Davies, The U.S. Bureau of Commerce and Labour, Whittaker & Co.; to the *Building Fund* from Messrs. W. Golledge, A. P. Hutchinson, R. F. Looser, F. S. Miller, J. T. Morris, H. C. Silver; and to the *Benevolent Fund* from Messrs. G. J. Gibbs, R. Robertson, H. C. Silver, W. C. P. Tapper, J. G. Wilson, to whom the thanks of the meeting were duly accorded.

The meeting adjourned at 9.30 p.m.

The following paper was read and discussed :—

TECHNICAL CONSIDERATIONS IN ELECTRIC RAILWAY ENGINEERING.

By F. W. Carter, M.A., Associate Member.

(Paper read January 25, 1906.)

Introduction.

In preparing a paper on the use of electricity as the motive power for railways, an author is apt to be embarrassed by the wealth of material to hand, and to find some difficulty in so defining the scope of the paper as, on the one hand, to furnish an adequate treatment of the particular branch of the subject chosen, and on the other, to avoid divagation into some of the many interesting by-paths which the subject offers.

It is proposed in the present paper to deal in a general way with the technical side of the electrification problem, neither entering to any great extent on the larger questions of economic engineering nor including descriptions of apparatus and material. The technical engineering will be found a sufficiently extensive subject for the purpose in view, whilst its importance can be gauged from the fact that general questions of finance and economic engineering can only be entered upon after a full technical investigation of the case in hand. It is, perhaps, because generalisation has been attempted without detailed investigation that so much of a misleading character has been published on this subject, tending to create and foster the idea among railway men that electrical engineers do not really grasp the conditions of railway work, or, like much that has been written on the single-phase question, raising expectations that are not likely to be realised.

In the course of the paper the author will give details of the methods employed in investigating the preliminary and exact engineering features of the electrical system, basing his work for the most part on the use of continuous-current railway motors, as applied to suburban service under conditions obtaining in this country. The methods employed will, however, be quite general, and applicable to other systems than that particularly considered.

The complete determination of the engineering features of an electric railway system necessitates a large amount of careful and detailed work in order that every part may be framed adequate for its duty and no part excessive. The labour involved in full investigation is, however, amply recompensed by the saving in capital outlay arising from the avoidance of superfluous plant, and the minimised

operating troubles and smaller expenses arising from the plant being suitable and sufficient for the requirements.

The engineering problem can be, and should be, attacked in a strictly logical manner. Beginning with the requirements of the system in respect to the moving of passengers or goods, a suitable train-driving equipment is first determined. The power and energy consumption of the train is then computed and the daily traffic estimated. Afterwards the generating plant and distributing system are laid out to suit the traffic requirements. The general process is simple, but every particular case will be found to disclose a host of special circumstances, modifying the details of the engineering scheme and calling for the exercise of great care and judgment.

The size, importance and location of the system will affect the engineering details throughout. In a system operating but few trains, these may with advantage be made smaller and arranged to accelerate at a lower rate than might be advisable and practicable in the case of a large and crowded system, in order to diminish the overload capacity necessary in generating and distribution systems, since this is likely to govern the capacity of the plant. Suitable provision must always be made to minimise the trouble and delay due to a breakdown, but the amount of capital that can be economically sunk in spares, duplicate feeders, and standby plant will depend largely on the importance of the system.

The chief classes of service between which it appears necessary to distinguish for the purpose of this paper are: (1) urban and suburban, (2) branch line and inter-urban parliamentary, (3) long-distance express, (4) goods. These differ in their requirements chiefly with respect to (1) rate of acceleration and speed up to which it is necessary to maintain the maximum rate, (2) behaviour on grades, (3) maximum speed attainable on level track. The chief electrical systems available for railway service are: (1) the continuous-current system, (2) the single-phase alternating-current system, (3) the polyphase system employing induction motors. There are, therefore, numerous alternative combinations of service and system, many of which can, however, be disposed of when the general principles have been elucidated.

General Dynamics.

The action of a railway motor depends practically on two variables only, and for a motor whose characteristics are known, when the voltage and current are given, the speed and tractive effort at the driving wheels are determined. The effect of the motors on the train depends upon, (1) weight of train, (2) inertia of rotating parts, (3) train resistance.

The weight of train to be employed in calculating the acceleration due to any force is a certain spurious "effective weight," composed of the true weight and an increment due to the rotation of the wheels and armatures. This increment is not difficult to obtain and will be merely stated here. If W be the weight of a wheel, r its radius at the tread, and k

its radius of gyration, the increment of weight due to the rotation of the wheel is W $\left(\frac{k}{r}\right)^2$. In an average steel railway wheel $\left(\frac{k}{r}\right)^2 = 0{\cdot}6$ approximately. If W′ be the weight of an armature, r' its radius, k' its radius of gyration, and γ the ratio of gear reduction, the increment of weight due to the rotation of the armature is W′ $\left(\gamma \frac{k'}{r}\right)^2$ = W′ $\left(\gamma \frac{k'}{r'}\frac{r'}{r}\right)^2$. For a continuous-current armature $\left(\frac{k'}{r'}\right)^2 = 0{\cdot}5$ approximately. Thus if W = 800 lbs., W′ = 1,600 lbs., $\gamma = 3$, $\frac{r'}{r} = \frac{1}{2}$, the addition for rotary inertia will be approximately 480 lbs. per wheel and 1,800 lbs. per armature.

In the case of suburban trains operated by continuous-current motors, the amount to be added on account of rotary inertia will usually be some 8 or 10 per cent. of the weight of the train, whilst with single-phase alternating-current motors the increment may amount to double as much, on account of the greater number and weight of armatures and their generally higher peripheral speed.

The forces resisting the motion of the train consist of the easily calculated positive or negative component due to grade—proportional to the actual weight of the train—and the rather uncertain "train resistance," composed of journal and flange friction, air resistance, etc. There is a lack of reliable data on the resistance offered to the motion of electric trains, which it is hoped will soon be supplied. The classical results of Aspinall * were obtained from measurements made behind a locomotive and tender, and accordingly do not include the head resistance, which is a very important element in the case of electric trains of two or three coaches. The Berlin-Zossen † high-speed train resistance tests were made with a single coach of totally different type to those usually employed in this country. Pending the publication of more suitable data, the author has combined the results of the above-mentioned sets of tests to obtain the working curves of Fig. 1, which he has found to agree very fairly with the results of such isolated tests on electric trains as he has been able to make. The variable portion is expressed in terms of the dimensions of the train, rather than of the weight, since it must represent principally air resistance, and therefore at any speed can depend only on the external configuration of the train. The constant portion of the resistance, which is taken from the above-mentioned tests at such low speeds that the static resistance just ceases to be apparent, is probably expressed with sufficient accuracy as proportional to the weight, and appears to be 2½ lbs. to 3½ lbs. per ton. The total train resistance is therefore the amount deduced from the curves of Fig. 1, increased by 2½ to 3½ lbs. per ton.

A light train of given external dimensions will, except at low speeds, meet with almost as great a resistance as a heavier built one of the same

* *Minutes of Proc. of Institution of Civil Engrs.*, vol. cxlvii. p. 155.
† *Journal of Institution of Electrical Engrs.*, vol. xxxiii. p. 894.

dimensions. A train of many coaches experiences much less resistance per coach or per ton than one of two or three coaches, particularly at high speeds. These facts are allowed for in the curves of Fig. 1. A long-distance high-speed train should, for efficiency, be composed of many coaches, whilst the weight is a secondary consideration. A frequently stopping low-speed train, on the other hand, should be built light, but whether it is composed of few or many coaches is of small importance as far as efficiency is concerned.

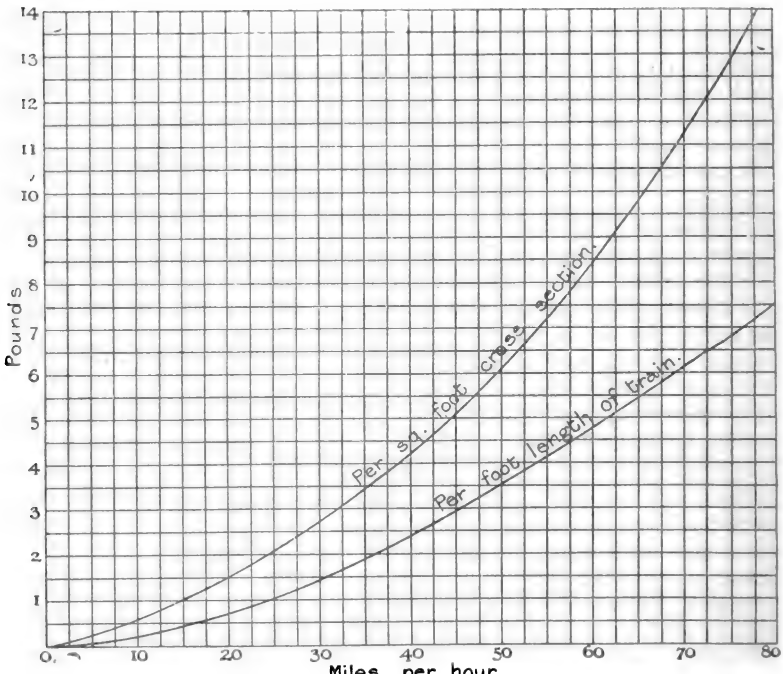

FIG. 1.—Train resistance curves, giving the variable component of train resistance.

The resistance due to the friction of brushes, motor journals, and gears, is usually charged to the motors, the tractive effort of which is supposedly measured at the rims of the driving wheels. It accordingly does not affect the train resistance during the time power is being supplied to the motors, but should be included during the time of coasting or drifting.

Of the energy supplied to the train, part is dissipated in motors and controlling apparatus, part is employed in overcoming train resistance, whilst the remainder imparts kinetic energy to the train and is dissipated during braking. The proportions of the several components are shown in Fig. 7 for typical suburban service employing continuous-current motors. The energy required to overcome train resistance

amounts very nearly to two watt-hours per ton-mile for every pound per ton train resistance. The kinetic energy dissipated during braking varies as the effective weight of the train, and as the square of the speed when brakes are applied. The energy dissipated in motors and gears will be some 10 or 12 per cent. of the input, whilst from 6 to 12 per cent. will usually be dissipated in starting rheostats. In the single-phase system the losses in motors, gears and controlling apparatus will usually be at least as great per ton-mile as in the motors, gears and rheostats of the continuous-current system, chiefly on account of the much lower efficiency of the motors. It will be seen that, in suburban work, a considerable fraction of the energy is dissipated during braking. In order to reduce this, suburban trains should be built as light as practicable, and run at as low a maximum speed as is consistent with the required schedule speed. A high rate of acceleration and a high rate of braking retardation are therefore desirable, since with these given the maximum speed can be kept down without diminution of schedule speed. As a general rule the best gear to employ with the motors is the lowest speed gear that will perform the service with a suitable margin for eventualities, provided, of course, that there is sufficient weight on driving wheels to stand the high accelerating tractive effort of a low-speed gear. It will be seen from Fig. 4 that the energy consumption is considerably affected by the rate of acceleration, particularly when stops are frequent and speeds high.

Whilst discussing energy consumption it might be well to issue a warning against the abuse of the ton-mile basis. As long as we deal with a particular system of electrification, the energy consumption is well expressed in watt-hours per ton-mile, but in comparing different systems with one another it should not be overlooked that the weight of train incident to a system is also a factor in the energy consumption.

The continuous-current railway motor is characterised by the fact that within the limits of practicable and efficient operation it has a large range of torque and a moderate range of speed. As usually geared, it is possible to obtain a torque of ten to fifteen times that required to overcome the train resistance at the maximum speed attained on the level, the high torque being maintained until the speed reaches approximately a half of the maximum. The characteristics of this motor, however, are well known and need not be further discussed here. Fig. 2 shows these characteristics for a typical continuous-current railway motor.

The polyphase induction motor is also well understood. Its efficient range of torque is moderate and the corresponding range of speed very small.

Single-phase alternating-current railway motors are of two general types—the compensated series and the repulsion type. The former is characterised by having its range of practicable and efficient operation between synchronous speed and two or two and a half times as much; whilst the latter operates below and up to synchronous speed, above which the commutation is bad. Both types show the same general speed-torque characteristics—the range of torque being considerably

smaller and the range of speed somewhat greater than in the continuous-current railway motor.

Fig. 3 shows typical speed and tractive effort curves for the continuous-current, the single-phase alternating-current, and the polyphase induction motor. The scale of co-ordinates is arbitrary, and in comparing the several motor types together, the abscissa or ordinate of any curve may be supposed increased or diminished in such proportion as may be desired to render the comparison suited to the class of service considered.

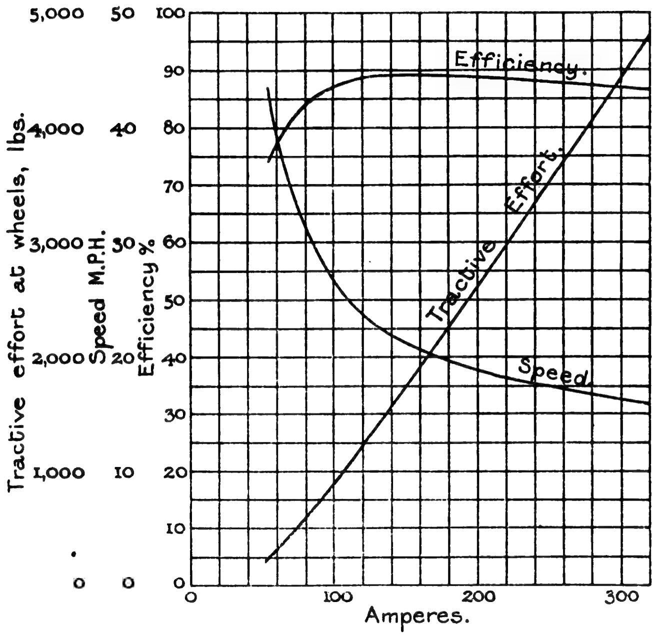

FIG. 2.—Characteristic curves of a continuous-current railway motor.

Knowing the train resistance, grade, and tractive effort of the motors at any speed, we can deduce the tractive effort available for producing acceleration, whence—from the effective weight of the train—the rate of acceleration. It is now a question of simple dynamics to deduce speed-time and speed-distance curves, whilst from the motor characteristics the power-time, current-time and other train characteristic curves may be deduced. The method of calculation need not be further entered into here, but it may be stated that for an isolated problem—such as the determination of train characteristics corresponding to the average schedule run for any service—by far the best procedure is by the point-to-point method. Where, however, it becomes necessary to make a calculation for an extended run involving stops at irregular intervals, and taking account of grades, curves, and

other circumstances affecting the running, the point-to-point method becomes exceedingly long and tedious. The author has devised an analytical method* of treating the problem which is fully as accurate as the point-to-point method, and much less laborious in its application to a general case, although involving some preliminary calculations which detract from its advantages if a simple problem only is in hand. The method is particularly worked out to suit the continuous-current railway motor, but can readily be adapted to the case of any motor having a drooping characteristic—such, for instance, as the single-phase alternating-current railway motor.

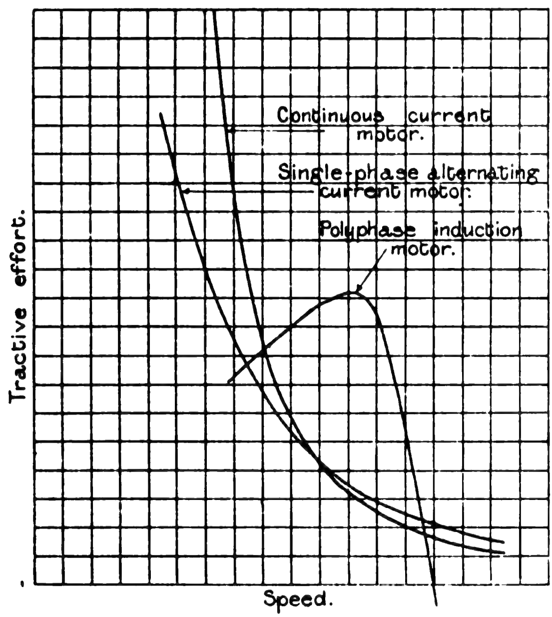

FIG. 3.—Comparative speed and tractive-effort curves of railway motors.

In regard to the reliability of such calculations as referred to above, and the accuracy with which the results represent the service performance of the train, it may be said that, if intrinsic circumstances—such as the motor characteristics and the weight of train—are known, and accidental circumstances, such as voltage and passenger load, can be fairly estimated, the calculated results will very closely indicate the mean service performance, and will agree well with tests made under suitable average conditions. No greater margin is necessary, therefore, in deducing a practical schedule from the calculations, or in determining the expected energy consumption, than must in any case be

* *Trans. American Inst. Elec. Engrs.*, vol. xxii. p. 133.

allowed in order to take care of low voltage, bad driving, unusual train resistance, or other detrimental deviations from average conditions.

The schedule that a given train is capable of, or the equipment required to maintain a given schedule, can generally be very closely computed by assuming as the distance between stops the average of the several actual distances, and, furthermore, assuming the track to be level. Both schedule speed and energy consumption will be nearly the same for this average run as the schedule speed and average energy consumption deduced from the actual runs. Unless and until

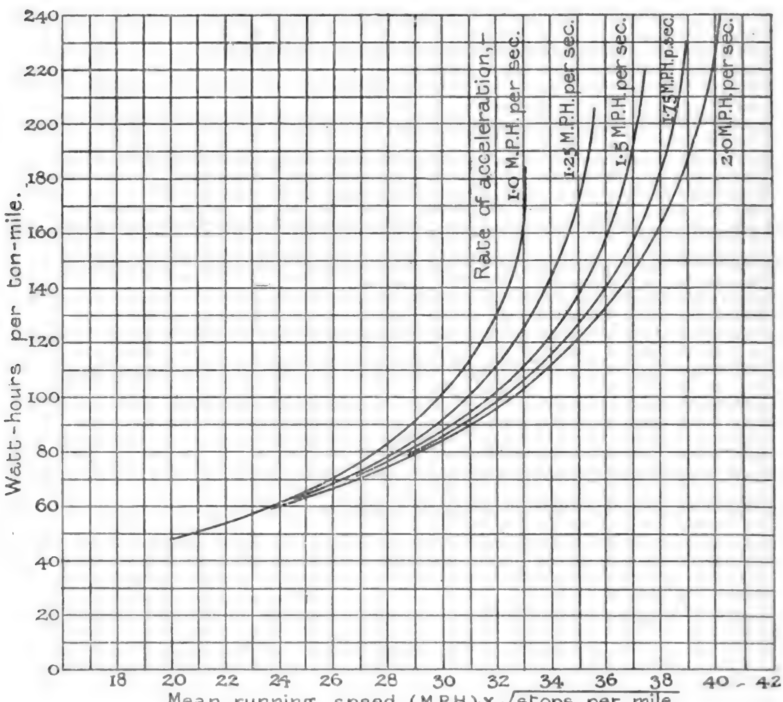

FIG. 4.—Energy consumption of trains operated by continuous current.

conditions are fully known, it is not, in the majority of cases, worth the labour to compute train characteristics for the actual runs.

If there is considerable difference of level between terminal stations, the averages in the foregoing statement must be assumed to apply to runs in both directions along the line. Moreover, the stations are supposed to be promiscuously distributed with respect to the grades. If, as in the case of the Central London Railway, the line is specially graded so that stations occur at the top of two grades, the schedule speed with a given equipment will be increased and the energy consumption diminished. If, on the other hand, the stations

are for the most part at the foot of two grades, the schedule speed will be decreased and the energy consumption increased.

The typical schedule run may be divided into four elements, corre-

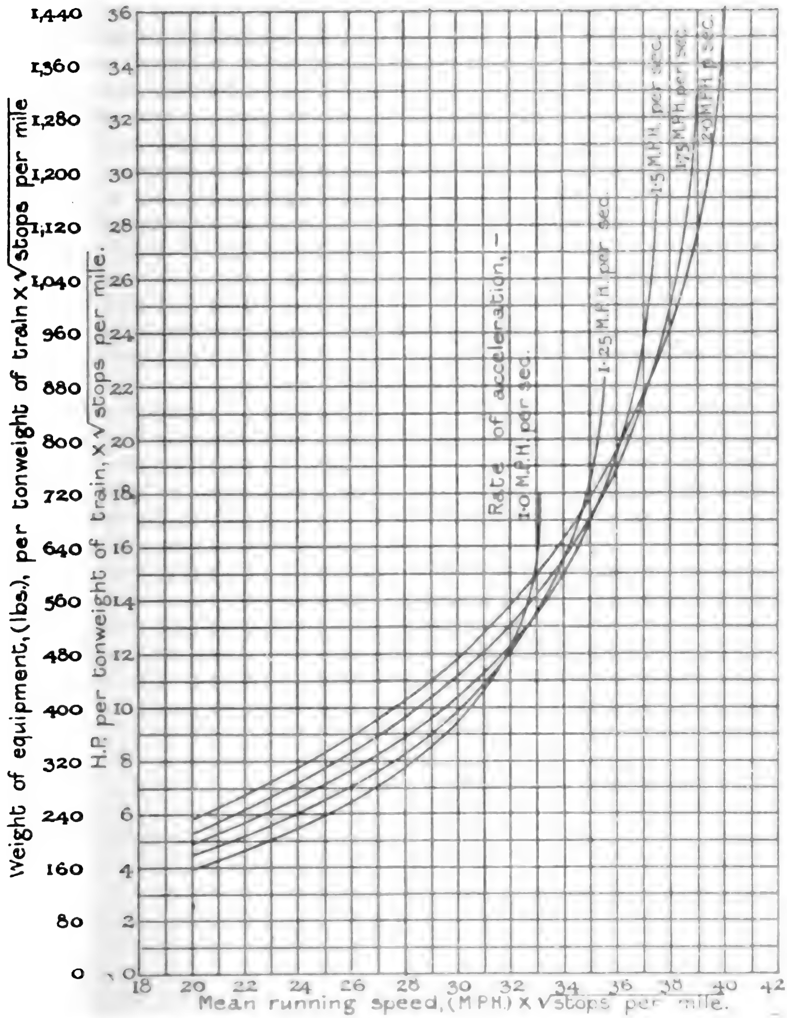

FIG. 5.—Power and weight of electrical equipment of trains operated by continuous current.

sponding respectively to (1) acceleration to the speed curve, (2) speed-curve running, (3) coasting, and (4) braking. Since any of these elements can be varied, it follows that a run can be made in many different ways. However, for any particular type of motor, if average

values be assumed for the amount of coasting and rate of braking, the remaining variables can, for practical purposes, be expressed in a system of curves, from which the particulars and performance of the train can be deduced. Such a system of curves for continuous-current motors as employed in suburban service is shown in Figs. 4 and 5, and these will be found useful and sufficient for preliminary calculations. In obtaining these curves, the characteristics of a normal railway motor were taken, and from them was deduced a set of train characteristics, corresponding to different rates of acceleration and different ranges of speed-curve running, care being taken that the motor was always employed as it actually would be in normal suburban service. The effective weight of the train was taken as 8 per cent. in excess of the actual weight. Coasting was assumed to occupy 17½ per cent. of the total running time. The average rate of braking was taken at 1·75 miles per hour per second. For train resistance, constant figures of 13 lbs. per ton while power is on and 15 lbs. per ton during coasting were assumed, it being impracticable to allow these figures to vary with the speed, since any point represents a variety of speeds, as explained below.

Fig. 6 shows typical train characteristics of this system corresponding to acceleration at 1·5 miles per hour per second. The three curves are of the same area, and the distance represented will be found to be one mile divided by the number of stops per mile, as of course it should be. In order to understand the reason for choosing the co-ordinates employed, suppose a particular run is made in t seconds, the distance being d and the number of stops per mile n, so that $nd = 1$ mile. Let the speed at any point be s.

Next consider a run in which both time and speed are changed in any the same proportion, x, so that the curve retains its shape but merely varies its linear dimensions in this proportion. The area will vary as x^2. We may therefore write :—

$$t' = x\,t,\ s' = x\,s,\ d' = x^2\,d.$$

But $$n\,d = n'\,d'.$$

$$\therefore n = x^2\,n', \text{ or } x = \sqrt{\frac{n}{n'}}$$

$$\therefore t' = \sqrt{\frac{n}{n'}}\ t$$

accordingly $$t'\ \sqrt{n'} = t\ \sqrt{n}$$

and $$s'\ \sqrt{n'} = s\ \sqrt{n}$$

It follows, therefore, that if we take (time × $\sqrt{n}$) as abscissa, and (speed × $\sqrt{n}$) as ordinate in Fig. 6, all speed-time curves having a definite shape will be reduced to a single curve, and all such runs will be represented by a single point on the curves of Figs. 4, 5 and 7. This method of treatment was pointed out to the author by Mr. E. H. Anderson, of the General Electric Company, New York, who has

employed it in deducing general curves for his own use, somewhat on the lines of Figs. 4 and 5.

Referring again to Fig. 6, and considering a speed-time curve of definite shape, the power required at any point will vary as the speed, and, therefore, inversely as $\sqrt{n}$. The energy consumption per run, varying as the power and as the time, will vary inversely as n. The energy consumption per mile, being n times the energy consumption per run, will be independent of n, and depend only on the shape of the speed-time curve. Accordingly Fig. 4 gives energy consumption directly in watt-hours per ton-mile.

Fig. 7, showing how the energy input given by one of the curves of Fig. 4 is finally dissipated, practically explains itself. It will be seen that with little speed-curve running the loss in braking predominates,

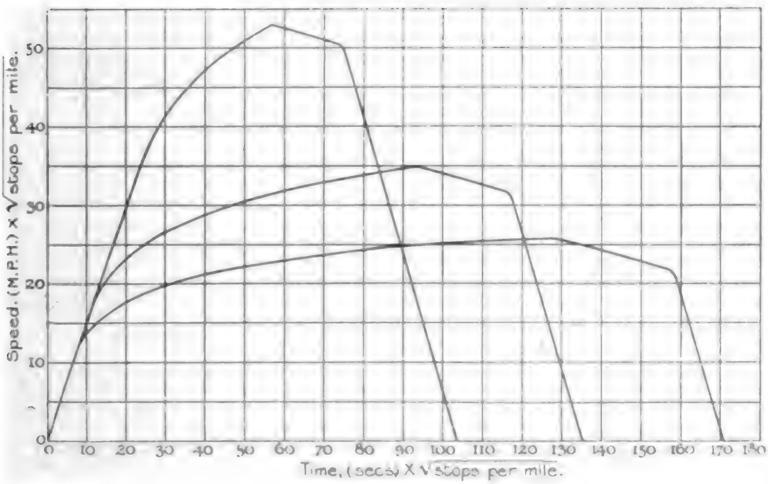

FIG. 6.—Typical train characteristics for trains operated by continuous current.

whilst with much speed-curve running the energy is principally employed in overcoming train resistance. In other words, where stops are frequent the total energy consumption depends largely on the weight of the train (see page 234), and where infrequent on the train resistance. Series-parallel motor-control is, of course, always assumed in these curves.

The power output of the motors during a run is very variable. It starts at zero and rises with the speed during the period of acceleration on resistance. Then, with the speed still rising, but more slowly, it falls off continually, due to decrease of tractive effort. The maximum power will be developed at the instant when all resistance is cut out, with motors in parallel—that is, when the motors are taking the accelerating current at full voltage. This is the power plotted in Fig. 5. It will usually, though of course not necessarily, be approximately the rated horse-power according to the rule of the American Institute of

Electrical Engineers given in the next section. This rule was, in fact, devised in order to provide a good test for the motors at the normal accelerating current—that is, the average maximum current at which the operation must be perfectly satisfactory. With the horse-power reckoned in the above manner, the weight of the electrical equipment is taken as 40 lbs. per horse-power. This is an average figure for the weight of motors and controlling apparatus employed in suburban service, which must, of course, only be treated as a first approximation.

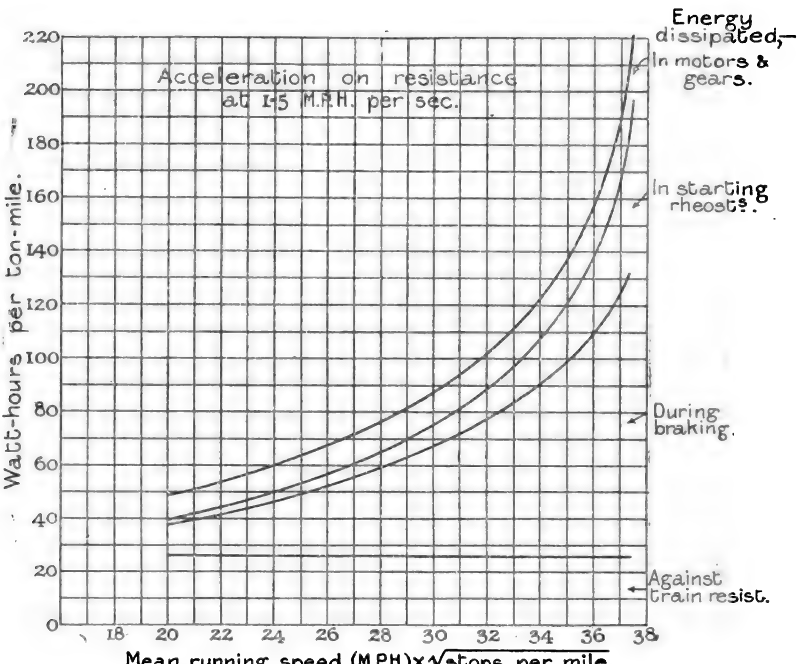

FIG. 7.—Dissipation of energy in trains operated by continuous current.

We are now in a position to estimate the weight of the train and the total power of the equipment, and to determine the power and number of the motors. A little trial and adjustment may be necessary, as the equipment will be heavier than the above figure (which is based on 150-H.P. to 175-H.P. motors), if many motors of small power are employed, whilst motor trucks are considerably heavier than trailing trucks. Moreover, the weight on driving wheels must be determined before the equipment can be finally settled on, in order to discover whether the adhesion is sufficient to stand the tractive effort of the motors. The accelerating tractive effort should not exceed about 17 per cent. of the weight on driving wheels in the case of trains driven by motor cars, operated by the multiple unit system of train-control—

wherein it is impracticable to sand the rails in front of all driving wheels in bad weather. Where locomotives are used, however, the average accelerating tractive effort may be allowed to amount to 24 or 25 per cent. of the weight on driving wheels, if efficient provision is made for sanding the rails in case of need.

Having taken account of all dynamical considerations and decided upon a suitable driving equipment, we should next determine the energy losses in the motor in order to discover whether its capacity is sufficient for the service. This matter is treated in the following section. If the equipment is found suitable from this point of view, we may proceed to determine the exact particulars of the average schedule run, the energy consumption per ton-mile and per train-mile, and the maximum and average power taken by the train. If deemed advisable we may determine the train characteristics for a whole journey, including the effects of the actual grades, slowing down where necessary at curves and junctions, and generally investigating the most suitable manner of operation.

Service Capacity of Motors.

In the preceding section we have shown how, from the requirements of the service, the dynamical characteristics of the motors necessary for driving the train may be deduced. It does not follow, however, that any motor having the required characteristics and capable of giving the required power without injurious sparking would be capable of standing the service continuously without overheating.

There does not at present appear to be a general agreement as to how railway motors should be rated. The most generally followed rule is that of the Committee of Standardisation of the American Institute of Electrical Engineers,* according to which "the commercial rating of a railway motor should be the H.P. output, giving 75° C. rise of temperature above a room-temperature of 25° C. after one hour's continuous run at 500 volts terminal pressure, on a stand, with the motor covers removed." The rule is, however, by no means universally followed in this country—the motors employed on the Liverpool Overhead Railway, for instance, are apparently rated on some other basis.† The rule was devised to suit the needs of continuous-current tramway motors, and whilst satisfactory for the purpose of comparing such motors with one another and useful in providing for a good running test at heavy load, which subjects the motor to a considerably higher temperature than would be aimed at in use, it furnishes no criterion as to whether the motor will suit a given service. Moreover, it lacks flexibility in specifying a test at 500 volts, which may differ considerably from the voltage for which the motor is designed, and at which it is intended to be operated. There is no practicable and simple method of rating a railway motor competent to express its real service capacity, and it is only by experience in actual service or by suitable

* *Transactions American Institute of Electrical Engrs.*, vol. xix. p. 1083.
† *Electrical Review*, vol. li. p. 21.

service tests that the sufficiency of a motor for its duty can be determined.

Service tests do not take account of *all* the circumstances incident to actual service, but they nevertheless form a satisfactory basis for an estimate of service performance. They are made by suitably gearing the motors and causing them to drive a car or train of suitable weight, making repeated and uniform runs on level track under known service conditions until the temperature of the motors becomes uniform. The large thermal capacity of the motors prevents the temperature appreciably following the intermittent applications of power, and a steady temperature is attained when the average rate of energy-waste in the motors balances the power dissipated in radiation and convection. If a number of such tests are made for different types of run, the results, suitably expressed, can be employed to estimate the performance in any service. A test, leading to one point on the curve, occupies from twelve to eighteen hours, and should be checked by a repetition test in order to reduce the effects of accidental circumstances. It will be seen, therefore, that the series of tests necessary to determine the service capacity of a motor will consume considerable time and money.

Amongst manufacturing firms, the General Electric Company of New York appear to have developed the investigation of service capacity of railway motors to the greatest degree, and their present eminent reputation for railway appliances is probably due in large measure to their scientific and painstaking methods of ascertaining the capacity and limitations of their apparatus and discovering its defects in service. A brief account of their methods of making service tests and expressing the results may therefore be given here.*

The runs of a test are made as far as practicable at constant voltage, constant mean accelerating current, constant time with power on, constant total time between starts, and constant distance run. Accurate records of current and voltage are obtained by means of recording instruments specially designed for this class of work.† Temperatures of armature and field coils by resistance and of field coils and frame by thermometer are noted hourly, whilst final temperatures of armature core and commutator are ascertained immediately on finishing the run. In expressing the results it is assumed that the temperature rise will be proportional to the energy loss in the motor, and that otherwise it will depend chiefly on the manner in which the energy loss is distributed between armature and field coils. Accordingly, from the ammeter and voltmeter records the best possible estimate is obtained of the average energy loss in the armature and the field coils—the armature core loss having been previously obtained from stand tests. Curves are plotted from the tests having as abscissa the ratio of armature loss to field coil loss (the so-called ratio of distribution), and as ordinate the temperature rise per watt loss, one curve being

* Armstrong, *Street Railway Journal*, vol. xvii. p. 289, and F. W. Carter, *Journal Inst. Elec. Engrs.*, vol. xxxii. p. 1104.

† *Trans. American Institute of Electrical Engrs.*, vol. xxii. p. 689.

plotted for the armature and another for the field coils. The appearance of the resulting curves for a large railway motor is shown in Fig. 8.

In making use of the thermal characteristic curves to determine the temperature rise in a motor proposed for a particular service, the average values of armature and field coil loss are calculated for the cycle of operations which the service involves. From these, the ratio of distribution is deduced; from the thermal characteristics, the temperature rise per watt loss; thence and from the losses we finally obtain the actual temperature rise of both armature and field coils.

The design of the motors should be such that for a service involving frequent stops—where they take the accelerating current for a considerable fraction of the time that power is on—the field coil temperature is the higher, whilst in a service involving much free running the armature temperature should be the limiting feature.

Fig. 9 is deduced from Fig. 8, and expresses the thermal characteristics

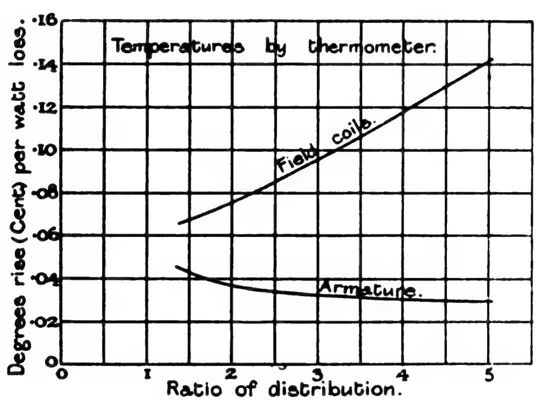

FIG. 8.—Service thermal characteristics of a railway motor.

of the motor in a different manner. It shows the total electrical loss which causes a limiting temperature rise in field coils or armature of 60° C. There is not a very large variation in energy loss for different classes of service, and as a first approximation one might affirm that, with a given frame, and a definite arrangement of perforated covers or other heat-dissipating devices, the permissible electrical losses are definite. A motor dynamically capable of a given service will therefore be suitable for continuous use on that service, provided the permissible electrical losses are not exceeded. These losses in a continuous-current railway motor of good design and considerable power usually amount to between 6 and 7 per cent. of the input.

The study of service capacity is of the utmost importance to the designer, who is thereby guided to arrange that the dynamical capacity of a motor shall correspond with its service capacity when used in the class of service for which it is designed, and so to distribute the losses

between armature and field coils that they may rise about equally in temperature in average service.

TRAFFIC.

Having finally settled upon the driving equipment and determined the maximum and average power taken by a train, it becomes necessary to make the best possible estimate of the amount of electrically operated traffic upon all parts of the system at all times, in order that the generating and distributing systems may be devised to suit the duty to be imposed upon them. In the case of an entirely new railway, the estimate must be based on knowledge derived from similar ventures elsewhere, modified according to the local circumstances. Where, however, it is in connection with an existing steam-operated system that electrification is contemplated, great assistance can usually be derived from a study of the time-tables of the system. These have been evolved to suit the needs of the locality served, and so form a secure foundation for the required estimate.

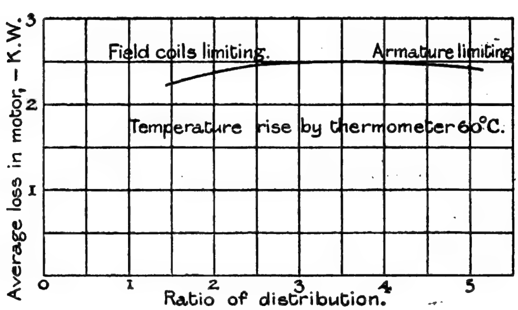

FIG. 9.—Service thermal characteristics of a railway motor.

As a general rule, when the directors of a railway begin to consider electrification, it is with the idea of increasing the passenger-carrying capacity of the system. In fact, except in the case of underground lines—where considerations of cleanliness and comfort may predominate—there is very little to be said in favour of converting from steam to electrical operation, if it is only required to handle the same amount of traffic as is already dealt with by the steam trains. Usually, therefore, it will be found that at some time in the day and at some part of the system, the traffic is already practically all that can be handled. Sometimes there is a terminus from which the empty trains cannot be withdrawn fast enough; sometimes there is a bottle-neck near a junction or terminus through which trains cannot be passed at more than a certain rate. In any case the limiting conditions should be made the subject of very careful investigation, and the corresponding limits on the electrified system should be estimated as closely as possible. Considering the great increase of traffic that usually results from an

improved service, it will generally be advisable to lay out the electrical scheme with the limiting traffic in view.

A very useful curve can be obtained from the time-tables of a steam road, by plotting the number of trains in service as ordinate against time as abscissa. Such a curve for a certain London suburban service is shown in Fig. 10. It may be taken as showing the probable general shape of the power-house load curve, no account, however, being taken of the variations in load at starting a train or cutting off power. If we are able to make a good estimate of the mean power required under electrical operation at the time of heaviest traffic, we can, by comparison of ordinates, infer approximately the power required at any other time.

Fig. 10 being a typical traffic curve for London suburban service under steam operation, we will here give some further particulars of the traffic represented :—

Total hours of service	20·5
Maximum number of trains running... ...	25
Total trains per day, up and down	450
Total train-miles per day	3,666
Total train-stops per day	3,809
Hence, stops per mile	1·04
Total train-hours per day	210
Hence schedule speed, m.p.h....	17·46
And average number of trains running...	10·25

It will be seen that the average number of trains running is only 41 per cent. of the maximum. The average during the time of light service is approximately 34 per cent. of the maximum.

In such a system one would expect to find, say, 27 trains in service, three as standby, and two undergoing renovation or repair, making a total of at least 32 trains allocated to the service. Each of these 32 trains, therefore, makes an average of 115 miles per day, whilst the 27 in actual service can only make an average of 136 miles each during the day.

The above applies particularly to steam operation, but if we regard Fig. 10 as showing the general shape of the load curve, it is probably sufficiently correct for the same railway when operated electrically. During times of light traffic the trains would probably be larger in number and lighter in weight under electrical than under steam operation, since light trains can be efficiently operated electrically. If we reckon such trains as fractions of standard trains, the shape of the traffic curve will usually remain practically unchanged, and this curve, together with the above schedule of particulars, will form a reliable basis for the estimate of probable traffic.

A well-known and useful method of representing the traffic is by means of a so-called graphical time-table. This is really a system of approximate time-distance curves, distance being plotted as ordinate against time as abscissa for all the trains of the system. It is composed of straight lines joining the several stopping places. The graphical

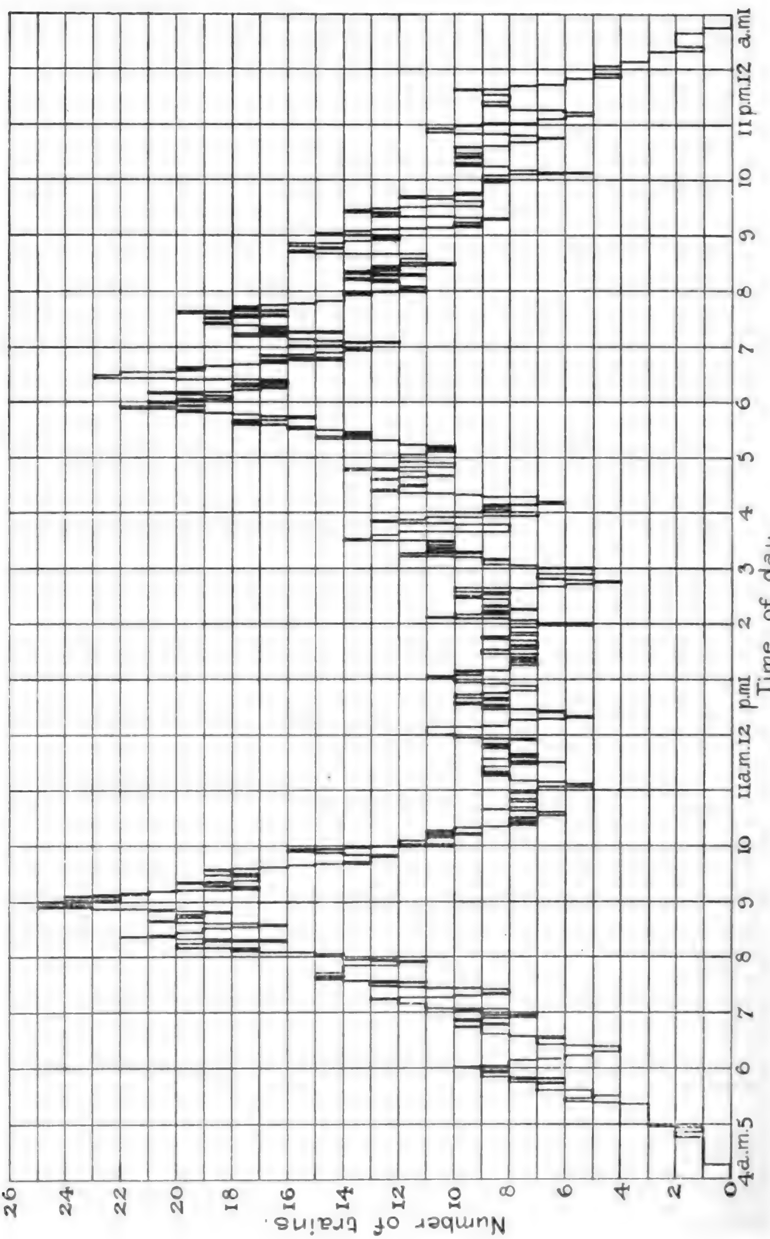

FIG. 10.—Traffic curve for suburban system.

time-table is used for several purposes by railway men, but we shall employ it as indicating the approximate position of the trains at any time, in order to aid in estimating the probable load on substations and the voltage drop in line conductors.

Distributing System.

In a system of any size there will usually be certain junctions from which several lines radiate, and which accordingly form natural distributing points, where one would place substations if otherwise practicable. One must also place a substation near each of the ends of a line, since, with the usual arrangement of low-tension feeders, the distance that one can feed to a dead end with a given drop in potential is only about one-third of the distance between adjacent substations on the line. Substations should, wherever possible, be placed at railway stations, for the convenience of attendants, inspectors, and visiting engineers, and to facilitate the delivery of supplies. Due consideration must of course be given to possible future extensions in arranging the distributing system.

The above considerations having been taken account of, and local conditions fully allowed for, the position of substations should be planned with reference to the potential drop between substations and trains. In the case of a completely insulated line equipment, such as that employed on the Metropolitan and Metropolitan District Railways, the waste of energy limits the mean voltage drop, whilst the necessity of efficient train lighting at all times limits the maximum. With a rail return, however, there is the additional restriction imposed by the Board of Trade on the voltage drop in uninsulated conductors.

By means of the graphical time-table above mentioned the position of the trains with the reference to the substations can be approximated, and the voltage drop in the conductor rails at any particular time determined. This should be done for a time of heavy load, and the worst condition to be anticipated in regular service should be judged, due allowance being made for probable future increase of traffic.

The position of the substations will in the end be a matter of considerable adjustment and compromise, the object being to feed the system efficiently, employing as few substations as practicable. On a system with many ramifications it is often impossible to prevent the substations crowding one another somewhat in certain places, but with care the layout can usually be made so that there is not very much waste from this cause.

In estimating the capacity of the machinery in the several substations, reference must again be made to the graphical time-tables, from which the number of trains fed by each substation at all times can be deduced. A table should be drawn up showing the momentary maximum and average load on each substation, both at the time of heaviest traffic and at the time of light load. The output of the substation may be taken as 5 per cent. in excess of the input to the trains. The maximum momentary output may generally be taken

as occurring when two trains are taking their maximum accelerating current and all other trains that can possibly be supplied from the substation are taking their average current. This rule is, however, subject to modification according to the locality of the substation.

When the above-mentioned table has been drawn up, the size and number of units in each substation can be determined. If possible, units of one size should be employed throughout the system, even if the capacity is sometimes greater than is absolutely necessary. The maximum momentary output of the substation should be taken to correspond with the maximum momentary overload of the machines in use. The load at times of heaviest traffic will indicate the number of units required, and the output during the time of light traffic will be found useful in determining the size of the units. Having settled upon the number of machines required for service, an extra one or two will usually be included in each substation to serve as standby.

In the case of rotary converter substations, the total capacity of the installed machinery will usually be some 40 or 60 per cent. greater than that installed in the generating station for supplying power to the trains. The excess is chiefly required on account of the exceedingly bad load factor of a substation, which necessitates an installation far greater than the mean load would indicate. In this respect the transformer substations of a purely alternating-current system show to great advantage. Transformers can be designed to stand five or six times the rated load for short periods without injury or excessive voltage drop, and two or three times for an hour or two without excessive heating. In such a system, therefore, the continuous capacity of substation plant will usually be less than that of the generating station plant, since the former may be laid out to suit the mean all-day load, whilst the latter must suit the mean load at the time of heaviest traffic.

In a continuous-current system the all-day efficiency of distribution from generating station bus-bars to trains is usually in the neighbourhood of 78 per cent. In a well-designed alternating-current system this efficiency would probably approximate to 87 per cent.

Generating Plant.

The position of the generating station for a suburban system will be chosen principally from considerations of available sites, suitable subsoil, and facilities for obtaining water and coal. Only after these have been taken account of will the high-tension feeder system become the predominant consideration, and then mainly in reference to the question of cost.

By means of the traffic curve of Fig. 10, combined with estimates of the maximum probable traffic under electrical operation, the power required per train and the efficiency of distribution, a fair estimate may be made of the power required at all times of the day. The size of the units—which should be similar—will be largely governed by the load at times of light traffic, whilst the number of units will be deter-

mined by the mean power required during the highest peak of the load.

The units should be chosen as large as practicable from motives of economy, provided they can be fairly loaded at times of light traffic. At such times the mean load on a unit should not be less than a half of its rated load, even if there are but few trains in service, and may be practically the full rated load if there are a considerable number. The overload capacity of the units may then be depended upon to provide sufficient power for starting the trains. If, as is advisable and practicable under electrical operation, only trains of few coaches are run at times of light traffic, the proportional fluctuations of load will then be little greater than at times of heaviest load—when long trains will be in service. The generating plant should, however, for this class of work, be such as will stand very heavy temporary overloads.

Having decided upon the size of the unit, which in this, as in other cases, may be influenced by the available market of supply, we determine the number of units required to handle the heaviest probable load for such time as it is likely to last. These, with one or two additional sets installed as standby for use in case of emergency, will form the main generating plant.

Alternating Current Working.

The foregoing has been for the most part written round the continuous-current system of operation, and whilst the general method of treatment is independent of the system, there are many considerations having special reference to alternating-current operation, a few of which may well be given here. The most valuable features of alternating-current operation are consequent upon the possibility of supplying power to the trains at high potential. This makes practicable the use of much lighter line conductors than can be employed under continuous-current operation, and also requires fewer substations for a given loss in the line conductor network.

The use of the track or other insulated return circuit for the current requires consideration. The author has no information as to what amount of electrolytic corrosion is to be expected from alternating earth currents as compared with continuous, or what regulations are likely to be imposed to prevent damage by such currents. It is not, however, desirable to impose a limit to the difference of potential between points on the uninsulated return unless the method of measuring the voltage is very precisely set out. If the voltmeter be joined to two points in the conductor by pilot wires lying very close to the conductor, the voltage indicated will be little more than the CR drop. The alternating flux due to the current in the conductor will for the most part cut the pilot wire and produce an E.M.F. practically neutralising the reactance drop; thus the indication of the voltmeter will be the difference of potential diminished by this E.M.F. In order to indicate the true difference of potential between points on the conductor, the pilot wire should lie on the surface separating the lines of

force which close about the trolley wire from those about the return conductor. This is practically the horizontal plane at a height from the ground equal to half the height of the trolley wire. Fig. 11 gives the indicated voltage for the particular case of two copper wires, each of one square inch cross section and 200 inches apart, and shows that the true difference of potential between any two points on one of the wires, at a frequency of 25 cycles, is in this case more than seven times the CR drop, although readings anywhere between one and fourteen times can be obtained according to the position of the pilot wire.

The earth currents will, however, be affected in the same manner as the voltmeter current by the varying flux about the conductors. Thus if a water or other pipe runs parallel to the return conductor, the

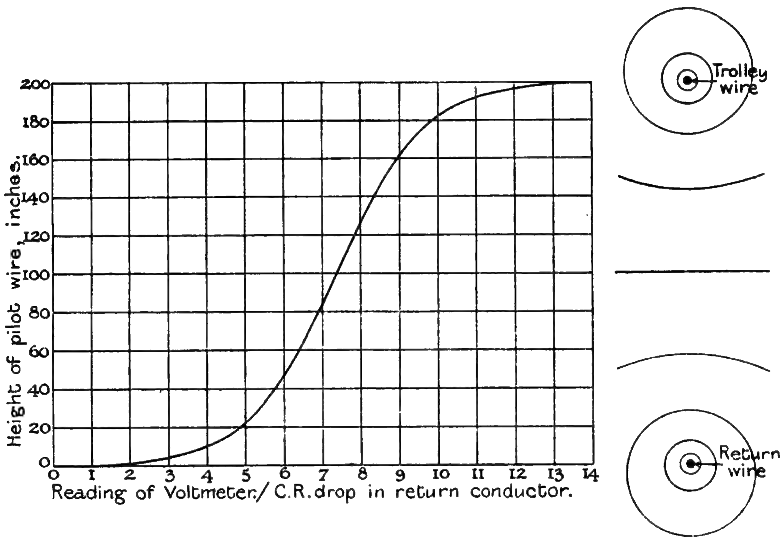

FIG. 11.—Apparent voltage drop in return conductor, using alternating current.

resultant potential difference tending to produce a current through earth and between two points in the pipe is that which would be indicated by a voltmeter connected to the corresponding two points in the conductor by pilot wires run in the position of the pipe. In the case of a rail return, where the conductor is of magnetic material, the varying lines of force in the iron itself will tend to confine the current to the outside layers of the conductor, and the CR drop will be several times as much for alternating as for continuous current.

Altogether, if earth currents are to be reduced to the same order as is found under continuous-current operation, and it is desired to place the substations as far apart, it will be necessary—taking account of the lower power factor and heavier trains incidental to alternating-current working, in addition to the foregoing considerations—to adopt a line

pressure of at least 6,000 volts, or else to install frequent track boosters to take care of the voltage drop in the earthed conductors. If advantage is to be taken of the high pressure to reduce considerably the number of substations, it becomes necessary either to adopt a completely insulated line conductor system, which much increases the difficulty of installation and working at complicated junctions, or to install track boosters, which adds to the expense. The latter will usually be found the most favourable alternative, as it is possible by means of these boosters, which are simple current transformers of ratio unity, to transfer entirely the voltage drop from the uninsulated to the insulated conductor. The best arrangement of boosters is probably that of the Oerlikon Company,* in which the track current is transferred by the boosters to a common return conductor running between substations. It is possible, however, to do without the return conductor by connecting the secondaries of the boosters across insulated joints in the track and introducing a small equalising wire as shown diagrammatically in Fig. 12. With this arrangement the track rails are em-

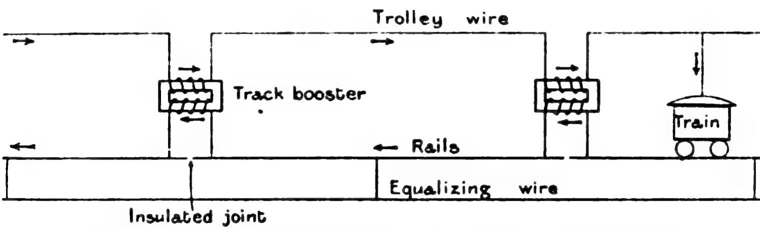

FIG. 12.—Track booster system for alternating-current operation.

ployed as return conductors. The boosters must, however, be closer together near the substations than in the Oerlikon system, and a greater number are accordingly required.

There is much of a general nature to be said in favour of the single-phase alternating-current system, and the author, in common with many others, founded great hopes on its development, believing that it would lead to a considerable increase in the electrical operation of railways. Careful investigation, however, reveals difficulties and disadvantages which compel the conclusion that the single-phase system as at present developed is not suited for a great part of the railway work likely to be required in this country (*i.e.*, urban and suburban work), and, moreover, shows no prospect whatever of being rendered satisfactory for the purpose.

In the present state of the art, the electrical features of new apparatus can be quickly developed and perfected, and the three or four years that this matter has been under investigation are sufficient to show its possibilities.

The weak feature of the single-phase system, as applied to this class of work, lies in the driving-motor. This has a much smaller

* *Elektrotechnische Zeitschrift*, vol. xxv. p. 313.

range of power than the continuous-current motor, whilst its electrical efficiency is considerably lower. The compensated series type of motor has a somewhat higher efficiency than the repulsion type—mainly on account of its lower rotor losses. Its efficiency is, however, necessarily lower when operated as an alternating-current motor than when operated as a continuous-current motor, and this again is lower than it would be if the motor were specially designed for continuous-current operation. Moreover, the energy consumption per ton-mile will usually be greater than in the continuous-current system, on account of the lower efficiency and less favourable speed-torque characteristic of the motor. Altogether the electrical losses in the motor are much in excess of those in the continuous-current railway motor, whilst, on account of the more compact internal construction, a motor with a given outside shell will be some 15 or 20 per cent. heavier.

We have seen that the rating of a continuous-current railway motor gives no information as to its service capacity, but is only useful in comparing motors of the same kind with one another. The method of rating the single-phase alternating-current motor is equally arbitrary, and is useless for the purpose of making a service comparison with the continuous-current motor. In suburban service, as we understand it in this country, a single-phase railway motor with a given outside shell has little more than half the service capacity of the continuous-current motor having a similar shell, which in such service is liable to be employed to its utmost capacity. This, we have seen, is equivalent to saying that the electrical losses in the motor are nearly twice as great, as compared with the input, as obtain in the continuous-current system. In suburban service it is practically necessary to employ multiple unit trains, with the motors geared to the axles of coaches, where they must be capable of operating practically enclosed and without attention for long periods.

The result of the above is that the alternating-current equipment is considerably heavier than the corresponding continuous-current equipment, the increased weight of the train itself requiring more motors. If we charge to equipment-weight not only the weight of the motors, transformers, and controlling apparatus, but also the excess of weight of the motor trucks over trailing trucks, and of the heavier underframe required to carry the transformers, etc., it is not too much to say that the single-phase system has an equipment weight per ton from two and a quarter to two and a half times as great as the continuous-current system, whilst an equipped and loaded train of given capacity may be some 30 or 40 per cent. heavier on the former than on the latter system. In the foregoing we refer particularly to the somewhat severe conditions of English suburban service. The objection, however, is more general than this, as will be seen by reference to the published weights of some single-phase cars. On the Indianapolis and Cincinnati Traction Company's single-phase line the cars, equipped but not loaded, weigh 96,700 lbs.* each. These are large corridor cars 55 ft. long and seating

* *Street Railway Journal*, vol. xxv. p. 173.

54 passengers each. They are of the type usually employed on American interurban lines, which, when designed for continuous-current operation, weigh from 60,000 to 70,000 lbs. each complete with equipment. Again, the car on the Ballston Line of the Schenectady Street Railway, which seats 44 passengers, weighs, when fully equipped, 60,800 lbs.,* although the underframe and trucks were not intended to carry such an equipment, and are rather light for the purpose. If furnished with an equivalent continuous-current equipment, however, the weight would not exceed 50,000 lbs.

We can now see why, under suburban conditions, the single-phase system compares very unfavourably with the continuous-current system. What with the heavier train and greater energy consumption per ton-mile, the energy consumption per train-mile, for trains of given capacity, will generally be quite 45 per cent. greater under single-phase than under continuous-current operation. Allowing for the higher efficiency of distribution in the former of these systems, the power and energy generated must still be some 30 per cent. greater. This requires 30 per cent. greater capacity in the generating plant, the cost of which will almost wipe out the saving on the substations, whilst the 30 per cent. greater annual generating costs will far exceed any possible saving in substation maintenance and supervision. In a compact system operating frequent trains—such as the usual urban system—the substation expenses are insignificant. The following proportions have been found to hold in reference to the Manhattan Elevated Railway :—

Generating and Substation Expenses:	%
Maintenance, power station	9·0
Operation, power station	85·0
Maintenance, substations	0·5
Operation, substations	5·5
	100·0

A properly installed overhead conductor system, insulated for high potential, will be at least as costly as a third rail, whilst the single-phase train equipments will be two or three times as expensive as the continuous-current equipments for corresponding trains. In fact, taking account of all circumstances, the single-phase system, when compared with the continuous-current system on the basis of equal traffic capacity, costs considerably more to install and considerably more to operate in the class of service under discussion.

The test of good engineering is ultimately a financial one. A certain result must be attained by such more or less prescribed means as will produce the greatest return on the necessary outlay. An increase of capital expenditure is therefore only justified if, by an improvement in facilities or decrease in expenses, an adequate return results. No such claim can be made on behalf of the single-phase system as compared with the continuous-current system in suburban service, and, unless

* *Engineering*, vol. lxxviii. p. 775.

prescribed limitations form a bar to the employment of the latter system, the former must be condemned.

The speed-torque characteristic of the single-phase motor is more suitable for high-speed service with few stops than for suburban service. A low rate of acceleration would here be no disadvantage, whilst the smaller range of power-output would avoid the large drain of power which the continuous-current system would show when starting a train in such service. Moreover, the energy consumption would depend principally on the train resistance, which would not be increased greatly on account of an increased weight of train. It would probably be necessary, however, to concentrate the equipment on a locomotive, where the motors might be artificially cooled—a course hardly practicable when they are carried on the axles of the coaches.

Some of the disabilities of the single-phase system disappear at low speeds, where the equipment weight is in any case a smaller fraction of the train weight and its increase therefore of less importance. Again, a service involving infrequent stops and moderate speeds, where the input per ton is small and the motor losses can accordingly be kept within reasonable limits, may often prove quite suitable for operation by the single-phase system. In short, this system shows promise of having extensive but by no means universal application to railway work.

The polyphase system, employing induction motors, has the disadvantage of requiring two or more overhead conductors, which complicates matters considerably at junctions, although it is not so serious an objection on continuous track. It is not well suited for suburban or other service in which stops are frequent and a high rate of acceleration necessary. With tandem-parallel control about one-third of the input during the time of controller acceleration is wasted in rheostats, and since controller acceleration is continued until practically full speed is reached, after which the power required is small, the waste in rheostats is nearly one-third of the whole input if stops are frequent. It is true that some of the energy of the moving train can be recovered when stopping, but only by imposing extra duty on the motors and so diminishing their service capacity. There is not the long range of efficient speed-curve running which characterises the continuous-current motor, the change from accelerating to free-running being almost sudden. The equipment weight, moreover, for suburban service is almost as high as in the single-phase system.

The polyphase system is practically confined to trains drawn by a single locomotive or motor coach. A small difference in the size of the driving wheels would result in a considerable inequality in the loading of the motors, and if some of the wheels are new and others old—as would be sure to be the case at times with multiple unit trains—some of the motors would do all the work and might even drive others as generators. The difference in size of the wheels is almost without effect in the continuous-current and single-phase systems.

Since the motor runs at nearly constant speed, the power-output is practically proportional to the torque. Thus the variations of the load

on the generators, due to acceleration and grade resistance, is much greater for this class of motor than for continuous-current motors, and is accentuated by the return of power to the line on down grades. This return of power must nevertheless be reckoned as one of the advantages of the system.

The strong feature in the polyphase motor, as compared with that of other systems, lies in the absence of a commutator, whereby the most frequent source of trouble is avoided. The motor is a good mechanical apparatus, with nothing particular to get out of order, and one could afford to sacrifice many advantages for the sake of employing such a motor for train driving. The weakest feature lies in the small air-gap necessary, which requires exceedingly good and well-designed bearings. These, however, can be provided without difficulty.

For a class of service to be suitable for this system of operation it must be such as will provide the motors with an efficient load during the greater part of the time they are taking power. A mountain line can be satisfactorily operated by polyphase motors, since the continuous grades furnish a sufficient load and there is no need to carry excessive motor capacity to provide for acceleration.

In fairly level country, goods or other service, in which stops are infrequent, and the acceleration therefore of small importance, might very well be operated by the polyphase system. High-speed long-distance service is particularly suitable, the high train resistance making the grade resistance of relatively smaller importance, so that during free-running the motors can be arranged to operate near the load of highest efficiency.

Conclusion.

The chief immediate developments in the direction of electric traction on railways are to be looked for in urban and suburban districts, where the increased schedule speed and the greater capacity of an electrically operated railway could be relied upon to develop the necessary traffic, whilst frequent and regular trains would do much to prevent the loss of traffic to tramways, so often deplored by railway directors at the present time. It is these considerations rather than the possible saving in operating expenses which constitute the case for the electrification of suburban lines. If it is desired merely to handle electrically the traffic at present handled by steam, the saving in operating expenses would not pay 1 per cent. on the capital sunk in conversion. For instance, the railway of which particulars are given above,* is thoroughly up-to-date in its operation, and typical of a well-managed London suburban system. To operate the same trains electrically the extra capital to be provided would amount to approximately £30,000 for each train in service. We have seen that the trains in service make an average of 136 miles per day, or, say, 50,000 miles per annum. It is evident, therefore, that a saving of nearly 1½d. per train-mile is necessary to pay 1 per cent. interest on

* Page 247.

the capital expended in electrification. Since the same trains are assumed, there can be very little saving anywhere unless it be in coal, which only accounts for about 3d. per train-mile in steam operation.

Taking all things into consideration, the continuous-current system appears by far the most suitable for suburban service in this country, and there are no present indications that it is likely to be superseded for this class of service. Our suburban trains usually make good schedule speeds in spite of the frequent stops, but we must expect to improve on the speeds under electrical operation. Such service is very severe, and it is not every motor capable of rotating the wheels that can be said to be sufficient for the service. Certainly the speeds on the present London electrical systems are not excessive, being little greater than is practicable on steam-operated lines of similar nature. Considerable improvement should, however, be aimed at in suburban operation about a town of the size of London, in order to bring distant suburbs within easy reach of the city. The Liverpool-Southport service, in which the schedule speed is thirty miles per hour, with stops less than a mile and a quarter apart, could hardly be effectively and efficiently operated otherwise than by the continuous-current system.

In one respect the London suburban service on such systems as the Great Eastern Railway will afford an engineering problem differing considerably from those with which we are familiar—the trains at times of dense traffic will be considerably heavier than has been usual in electrical suburban service. If an increased number of passengers have to be carried it will hardly be practicable to diminish the length of the trains, which is only limited by the length of the station platforms. The use of excessively heavy trains is fraught with consequences likely to lead to a radical departure from the present standard practice. The coaches will probably be of the present compartment type, on account of their greater seating capacity as compared with the corridor type, and, in fact, the present coaches could be largely employed in making up the trains. The chief disadvantage of the compartment type is that when trains are well filled time is lost by intending passengers in seeking a compartment, so that longer station stops are necessary than when the corridor type of coach is employed.

The objections to the continuous-current system, when heavy trains are to be employed, arise for the most part from the necessity for using a third rail. This being accessible constitutes a source of danger, whilst it is exceedingly difficult to install at complicated junctions. Moreover, the system is hardly the most suitable for long-distance service, so that objection has been made to it on the ground that it cannot be generally extended throughout a railway system. This last objection, however, is of little weight, as electricity cannot compete with steam for general railway work in this country, so that universal electrical operation may be ruled out of account. The danger to workmen and others arising from the presence on the line of an accessible conductor at dangerous potential is patent, and can only be obviated by rendering accidental contact with the conductor

impossible. An efficient wooden protection for this purpose will add perhaps 5 per cent. to the total cost of electrification, so that the question of additional danger is not a very effective argument against the continuous-current system. The third-rail protection, moreover, by preventing short-circuits with track tools, is a valuable security against shut-down. It is worthy of note in this connection that the New York Central and Hudson River Railroad have adopted a completely protected third rail within their New York City electrical zone.*

The difficulty of installing line-conductors amongst the intricate switchwork and signal rods of a large terminus or junction is serious, and is increased fourfold, as far as a great portion of the London district is concerned, by the action of the underground railways in adopting an insulated return conductor instead of employing the track-rails as return. Where the trackwork is not too complicated, a single conductor can usually be installed, so that contact is never lost by the collector shoes, whilst even at the most intricate junctions it can always be located overhead. With a second insulated conductor, however, it is at such places practically impossible to secure continuous contact for both sets of collector shoes within the length of a locomotive or motor coach, and sometimes even of a long train. If the insulated return is adhered to throughout the London district, much rearrangement of track and signal rods will be needed at many termini and junctions. The chief argument in favour of an insulated return is that it enables the track-rails to be used for signalling purposes.

When we depart from suburban conditions and begin to consider classes of service in which the traffic is less dense and stations less frequent, we cannot formulate general rules as to the best system of operation, or even assert that electrical operation is good engineering. Each case as it arises must be considered on its merits, and a full technical investigation of the problem presented is necessary before any definite conclusion can be arrived at.

A class of traffic for which electrical operation might be expected to show to advantage is interurban passenger traffic, handled on the same lines as on the American interurban railways, *i.e.*, with single cars or small trains running at fairly high speeds and at frequent intervals. There are many districts in this country where such a system could hardly fail to attract considerable traffic—where, in fact, the tramways are already well patronised in spite of their low speed. Such districts as South Lancashire or the South Staffordshire Black Country offer excellent facilities for this class of service, and the network of railways in these districts would well repay electrification, the population being dense and the interdependence of industries requiring free and frequent communication.

Where stations are fairly close together, the continuous-current system will probably be found most suitable for this class of work, especially if the system forms a compact network. In case none but small trains are to be electrically operated, the track conductors may

* *Street Railway Journal*, vol. xxvi. p. 336.

be located overhead in the form of a trolley wire, otherwise a third rail will be necessary. The overhead system has advantages in industrial districts where there are a large number of goods-sidings whose switches and crossings add to the difficulty and expense of installing a third rail. At the present standard voltages, the weight of train that can be fed from a single overhead trolley wire is limited to perhaps 50 tons. There is, however, no real engineering necessity for restricting the operation to present standard voltages. If the mean speed desired is not very high,—considering the distance between stops,—it may often happen that alternating-current operation would furnish the most satisfactory means of attaining the end in view. Where stations are not less than two or three miles apart and the electrically operated lines do not form a too complicated system, a strong case could in many instances be made for the polyphase system. In general, however, it is probable that the single-phase system would be found the more advantageous for such work.

Another class of service for which electrical operation might well prove desirable is that on branch lines, where in many cases the traffic is not in itself sufficient to pay expenses, but is necessary to put country towns in communication with the main lines. These should be run as interurban tramways, operating a fairly frequent service of single cars or trains of two or three coaches and employing overhead line conductors. Such a system could be installed at moderate capital outlay, whilst a considerable saving in operating expenses would ensue on account of plant and operatives being more uniformly employed. The more frequent service would be expected to result in considerably increased traffic between towns and villages.

The best system of operation is a matter for investigation in particular cases, depending on considerations already discussed. It may be mentioned, however, that in the case of newly projected lines intended entirely for this class of service there is some advantage in adopting the continuous-current or the single-phase system, since very little grading is required if either of these systems is employed, the motors being capable of operating efficiently on much steeper grades than could be permitted in steam service. The former of these systems is particularly suited for operating where grades are excessive, on account of the large range of tractive effort and moderate range of speed of the motors. In the single-phase system the speed varies rather too much with change of train resistance to be quite satisfactory, but on the other hand the tractive effort can, within limits, be adjusted to the speed and grade by varying the potential difference between motor terminals—that is, by changing the running tap on the main transformer. In many cases the extra cost of electrification would be saved in the diminished excavation, and the lower cost of land due to the greater latitude of location possible when grades are unimportant. The light agricultural railways under consideration in some quarters should undoubtedly be electrically operated.

In a few places, such as between Liverpool and Manchester, and between Leeds and Bradford, it might be possible to inaugurate a very

high speed service on the lines indicated by the Marienfelde-Zossen tests, although it is a little doubtful whether the saving of time possible in these comparatively short distances would form sufficient inducement to create a paying traffic. Such lines running from London to Birmingham, Manchester and Liverpool, might attract considerable traffic, but could hardly be constructed against the opposition of existing companies, and as they would be largely special and reserved for the one class of traffic, it is improbable that they could be made to pay at present. Altogether there does not appear to be much prospect for such exceedingly high-speed lines in this country for some time to come.

The operation of our main-line trains would not be sensibly improved by electrification ; certainly no such improvement would be anticipated as would justify the necessary great outlay of capital. Where conditions are different, however, considerations which do not apply in this country may render general electrical operation desirable. In Sweden, for instance, where the locomotive coal is imported, whilst there are extensive peat beds and much water power, it is possible that general electrification may be justified. Here, however, the coal bill is not a very great item in the operating expenses, and we could not expect to save on it. Electrical operation is, therefore, economically feasible only for those classes of traffic in which some service advantage results. In the case of main-line traffic, no practical advantage would be gained by a higher rate of acceleration, or by running frequent small trains—in fact, at high speeds small trains would be uneconomical, however operated.* The usual arguments in favour of electrification, therefore, have no weight as applied to this class of traffic.

There is one consideration, however, which may become important on some sections of line, and this is that, with the limiting load gauge given, it is possible to obtain considerably more power from an electric than from a steam locomotive. The power practicable within the loading gauge imposes a limit on the trains which it may sometimes be desired to extend.

No particular advantage would in general accrue from the electrical operation of goods traffic. At docks, goods-yards, and like places, however, where there is much shunting, if there is an existing generating plant for supplying power to cranes, capstans, etc., it would undoubtedly be advantageous to employ electric locomotives in place of steam. The latter are very inefficiently employed in such service on account of the large amount of standing and starting necessary. With electric locomotives designed suitable for such work, the efficiency of the system would be much improved at trifling extra cost, whilst an improvement would also be expected in the load factor of the generating plant, so that the cost of additional power would be small. In some such localities the use of overhead wires would be objected to, and some form of surface-contact system would probably be found necessary.

In the present state of the art it is possible to determine very

* See page 234.

closely the technical details of the installation necessary for electrically operating any portion of a railway system. The limitations of any electrical system for the particular application can be judged and the best mode of operation determined. Moreover, the capital expenditure and operating costs can be closely estimated and the economically soundest scheme devised. In the case of the continuous-current system, the particulars of the installation can be predetermined in full detail, whilst an accurate forecast of the operating expenses can be made, the maintenance costs of the machinery and plant being already known from extended experience. When this system is employed, in fact, the predetermination of the electrical features can be made with all necessary accuracy, certainly with as high a degree of accuracy as the indefiniteness of traffic and conditions will permit.

Although, for reasons above stated, no general electrical operation of our railways is to be expected, we may yet look forward to many developments in railway work within the next few years. When the systems in course of installation, or already in operation, have been given full opportunity for proving their usefulness and reliability, and suitable methods of handling the traffic under the altered conditions have been perfected, the directors of most of our principal railways will realise the advantages of electrical operation in some portions of their systems. There is at present a little natural conservatism amongst railway managers, and a disinclination on the part of directorates to sanction the outlay of a large amount of capital when the best system of operation appears to the superficial observer still a matter of speculation. It is hoped that the present paper will serve in a measure to delimit the spheres of usefulness of the several systems of electrical operation, or at least to prove that the most suitable system can be determined in any particular case.

In order to prevent misunderstanding, the author wishes to add that the views expressed in this paper are entirely the results of his own study of the subject, and should not in any way be taken as representing the attitude of the company with which he is connected.

Discussion at Meeting of January 25, 1906.

Mr. Dawson.

Mr. Philip Dawson: May I first express my appreciation of the very able paper which we have had read to us to-night? It treats of a subject with which I am very familiar and in which I take particular interest. If in the course of this discussion my conclusions differ from those of the author, I hope he will understand that I do not wish to cast any reflections on the accuracy of his statements, which, I presume, are the results of his personal investigations, but merely to suggest that the motor he has experience of has not the characteristics of a satisfactory single-phase traction motor, which latter, although the author does not appear aware of it, is in actual existence to-day. On page 233 the author refers to the amount which has to be added for the inertia of revolving masses, and compares the amounts which must be added in the case of continuous and alternating current machinery. In the

case of continuous-current motors he says the amount will usually be from 8 to 10 per cent. of the weight of the train, and that with single-phase motors this would probably be doubled. I have investigated this point very carefully, and in the case of the single-phase motors which we are going to adopt on the London, Brighton and South Coast Railway only 13 per cent. has to be added for revolving masses, or only 3 per cent. more than the maximum which the author states should be added in the case of continuous-current motors. On page 235 the author suggests that the amount of energy dissipated by a rheostat in starting losses in the case of continuous-current motors is from 6 to 12 per cent., and that in the case of single-phase motors this would probably be greater, due to the very much less efficiency of these motors. Results with which I am personally acquainted do not bear out the author's conclusions. I find that, although the single-phase motor shows a smaller efficiency than a continuous-current motor, the efficiency is only about 4 per cent. lower than that of the very best continuous-current railway motors yet constructed; if we take into account the more efficient way of speed regulation due to the use of transformers instead of resistances, we certainly have a very much smaller loss in alternating-current motors than with continuous-current motors. On page 236 the author refers to some curves which are given in Fig. 3, where he compares the speed and tractive efforts of continuous-current and single-phase railway motors. I have only had a very short time to check the paper, but I have plotted out some results which I have obtained with alternating-current motors, and this curve practically coincides with the curve which the author gives here for the continuous-current motor. Mr. Dawson.

The author, on page 250, refers to the capacity of a rotary transformer substation as compared with the capacity of the generating plant which is required in connection with continuous-current installations, where, owing to the very large amount of power to be generated, and the large area over which it must be distributed, the current must be generated in the form of alternating or polyphase current, although it is used as continuous current. The author states that the total capacity of rotary converter substation machinery is from 40 per cent. to 60 per cent. greater than machinery installed in the generating station; in other words, the capital cost of the substation plant may be greater than the capital involved in the total generating plant. On to this must be added the capital cost of low-tension feeders, and nearly the whole of this large expenditure is due to the use of continuous-current motors, and is not required in the case of a single-phase installation. The author further on states that the overall efficiency in the case of a continuous-current system is about 78 per cent. From very careful calculations which I have had to make, I think he has rather overestimated that efficiency; I think it would probably be a good deal nearer 74 or 75 per cent. than 78 per cent., although I agree with him when he puts the efficiency of an alternating-current system at 87 per cent.; indeed, I think with a properly designed system that efficiency could be raised. The author, on page 251, has called

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attention to a very important property of the single-phase system, where he refers to the very much higher voltage which can be adopted in the conductors where single-phase current is used compared with where continuous current is used. This pressure at the present moment is standardised more or less between 6,000 and 6,500 volts. As far as I can see, there is no reason why this pressure should not be raised: in fact, at the present moment there is a line running in Switzerland, about fifteen miles in length, where the line pressure is 15,000 volts, and they have found no difficulties either in transmitting or collecting the energy at that very high pressure. At the bottom of page 252 the author refers to the low power-factor of the single-phase system. It seems to me that he must have done so under some misapprehension, because, if he takes the power factor of the continuous-current installation, he will find that there is practically no difference between the average power factor obtained with the single-phase system and that at present obtained with the continuous-current system where polyphase currents are generated and afterwards transformed to continuous current. It seems to me that the author is very daring in his statement on page 253, where he says, referring to the probable future of the single-phase current, that "Moreover, it shows no prospect whatever of being rendered satisfactory for the purpose." A great many members in this room will remember the time, not many years ago, when the mere possibility of a satisfactory single-phase motor being produced of such a size as would be required for traction purposes was considered ridiculous. At the present moment I am sure there is not a member in this room who would suggest that a single-phase motor is not an accomplished fact, or that it does not give very satisfactory results. It seems to me if this, which was apparently an impossibility four years ago, has been brought to pass, that even supposing the statements which the author has made were really justified by facts—which I do not concede—his statement that the future will not see the production of a satisfactory single-phase motor is unjustifiable in the light of past experience. On page 254 the author refers to the very much larger weights of single-phase motors compared with continuous-current motors. It is true that up to the present moment single-phase motors are slightly heavier than continuous-current motors, but I consider the disabilities of the single-phase motor have been very much exaggerated by the author, while its virtues have scarcely been referred to. To justify my assertion, I will give you the following figures. The weight of a 150-H.P. motor, rated on the American principle to which the author referred, is 2·7 tons, and the weight of a 115-H.P. motor rated exactly on the same basis is 2·4 tons. If we take the weights of two motor trucks, one set equipped with four 150-H.P. continuous-current motors, the other with four single-phase 115-H.P. motors—that is, simply the complete motor trucks, we find that the weight of the continuous-current motor equipment would be nearly 26 tons as against 27 tons for the alternating-current equipment. But in considering this question of weights, it is very important to bear in mind that there are other portions of a

Mr. Dawson.

train which must be taken into consideration besides the weight of either the motor equipment or the trucks, and there I refer to the weight of the car bodies. The author has rightly said that the electrification of existing railways is a commercial proposition, and that the electrification will never be introduced until the railways are thoroughly satisfied that by so doing they can improve their service and increase their receipts. The receipts will very largely depend on the accommodation which is given to passengers, and that again will depend upon the car body construction. There is not a railway manager in Great Britain who would for one moment hesitate in employing a motor car body weighing 15 tons if it gave better accommodation than a car body weighing 10 tons. At the same time there are different types of trucks which vary in weight according to the type of construction, and the difference in weight of a pair of such trucks would easily reach three tons. Therefore, the total difference in the weight between one type of car body in one type of truck and another type, leaving entirely out of consideration the question of the difference in weight due to motor equipment, would be 8 tons per car, or, taking a three-car train, which will probably be the normal size of train adopted for suburban traffic, will mean that there will be a difference due to car bodies and trucks alone of 24 tons per train, which is a great deal more than the maximum difference in weight of continuous and alternating motor equipments. As regards the question of multiple unit control, which the author refers to on page 254, I do not exactly understand his inference, as the multiple unit system is applicable to a single-phase system; in fact, practically the same apparatus which is used in conjunction with continuous current for multiple unit control is employed with single-phase motors, the only difference being that the multiple unit apparatus in the case of the single-phase is very much simpler and the parts are very much fewer than in the case of the continuous current. The figures which I have given you, and the few remarks which I have made, show that the author's statement on page 255, where he suggests that there are reasons why the single-phase system compares unfavourably with the continuous-current system as regards suburban traction, is not in accordance with facts. I will give you some further figures in support of this statement, which I worked out from actual experimental results in my possession. They are for a run on the level over a distance of 2,583 ft. There the running time of a train composed of two motor coaches, equipped with eight motors and three trailer coaches, the coaches and the trucks being exactly the same in the case of the continuous and alternating current system, was, in the case of the continuous-current system, 91·46 seconds, and in the case of the alternating-current system 92·25 seconds. The average efficiency was, in the case of the continuous current, 73·6 per cent.; in the case of the alternating current 74·2 per cent.; and the watt-hours consumed per ton mile for operating and braking, that is to say, including the amount required for operating the air-compressors, was, in the case of the continuous current, 68 watt-hours per ton mile as compared

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with 63 watt-hours per ton mile in the case of the alternating current. As regards acceleration, that was very much more favourable in the case of the single-phase than in the case of the continuous current, the continuous-current train requiring 37 seconds to attain a speed of 25½ miles an hour, whilst the alternating-current train attained 25·9 miles an hour in 22½ seconds. The rate of acceleration which the author refers to at the top of page 256 is very much more favourable in the case of single-phase than in the case of continuous current. I have recently had an opportunity of making some very interesting tests, with an apparatus which was designed by Mr. A. P. Trotter, of the acceleration obtained under actual running conditions with single-phase and with continuous-current trains, and the results are practically these: whilst with continuous-current trains giving a very high average rate of acceleration (which is due to the fact that the very high acceleration was gained at the beginning), we got 2 ft. 6 in. or 3 ft. per second per second just after starting, then falling down to 1 ft. and then 6 in. per second per second, with the alternating current the process was exactly reversed. We started out with an acceleration of about 9 in. per second per second for the first 100 ft. or 200 ft., and the acceleration then rose to nearly 2 ft., and remained constant at 2 ft. per second per second during the whole period of acceleration. I suggest that this curve of acceleration is a very much more satisfactory one for operating a suburban service than that obtainable with continuous-current motors. In connection with this whole question, there is one point which should not be lost sight of; and that is that it does not matter how much we electrical engineers are anxious to see our existing railways adopt electricity, unless we can prove to the satisfaction of the existing railway authorities, not only that electricity is more advantageous from their point of view, but also that it will not bring with it a train of very serious disadvantages, it is perfectly hopeless for us to imagine that electric traction will be introduced extensively within the next few years. From the very careful and very long investigations which I have had to make in connection with this subject, I have come to the conclusion that the consensus of opinion amongst railway men in the whole of Europe, and to a certain extent in America, is that if electricity is to take the place of steam for running ordinary suburban trains this will never be the case as long as the third and fourth rail are essential to its introduction. Under these circumstances it is evident that the continuous-current system must at once be put out of court. I myself believe that the very satisfactory results which have been attained with single-phase motors in the last few years are entirely due to the big electrical manufacturers having thoroughly realised that main-line railways are not going to adopt electric traction unless the third and fourth rail can be entirely dispensed with. In conclusion, I should like to express the hope that the author may alter the conclusions he has arrived at to the following extent: that our railways, as far as the suburban traffic is concerned, will adopt the single-phase system of traction for handling their

trains, which has shown itself the most suitable to fill their requirements. Mr. Dawson.

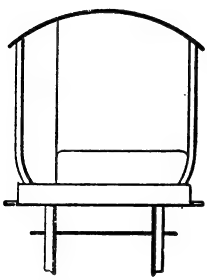
Mr. A. P. TROTTER: I quite agree with what Mr. Dawson has said about alternating current. Of course it has to be safe. Whether he is going to use 3,000, or 6,000, or even 15,000 volts, does not matter at all; it can be made as safe with one pressure as with another. The question of alternating-current electrolysis is raised, and some information is asked for. If I give any information, it simply describes my own personal opinions to-day, and if they are altered at any time, or if any official views vary from them, that is no affair of mine at this moment. There is such a thing as alternating-current electrolysis, and I have made several experiments on the subject. It may amount to about one-half of that due to continuous currents. On the Brighton and South Coast line the rails are on chairs, the chairs are on sleepers, the sleepers are on ballast, and the ballast is on high brick arches or on embankments. They are a long way from the pipes, and under those circumstances I do not see any objection at present to there being 20 volts drop on the rails. Nothing has been laid down, although something was promised. Years ago there was a footnote to one of the Board of Trade regulations to this effect: "The Board of Trade will be prepared to consider the issue of regulations for the use of alternating currents for electrical traction on application." A formal application has not been made, but I have said to those who are concerned that I did not see any harm in 20 volts drop. Of course the question is, how it is going to be measured, and that I have considered with some little care. The author has told us that merely putting a pilot wire on to the rails is not so very simple a question. That is the unfortunate part of alternating currents; they do not behave like continuous currents. The author has given a case where he takes a single trolley-wire and a single return conductor, and he shows that, under ordinary circumstances, the pilot wire ought to be between the two. That follows from ordinary simple mathematics. What is going to be the case in practice I cannot tell you exactly; but there would be at least two trolley-wires, four rails, about three feeders coming from the power house to the substation, a feeder probably from the substation to the points upon the track, and a track return into which the current is boosted out of the rails. I am glad I have not got to calculate where the pilot wire is to be, but I have already thought out what I propose to do, and it is this: I want to borrow a telephone wire running right out into the country at about right angles to the line for a mile or so and back again, enclosing a large loop. Then I want to have a pilot wire placed anywhere by the side of the track, in the most convenient place that can be found. Then we will compare the volts found on that pilot wire, and on any instrument that is used with it as an indicator, with the volts found on a loop with an electrostatic instrument; 20 volts is a very handy pressure to measure electrostatically. I think I am right—I should like to be corrected if I am wrong—that that is taking it at its worst. If you have a pipe running alongside the track picking up leakage Mr. Trotter.

Mr. Trotter. current from the rails, as the author points out, there will be an induced current in it which will choke back the leakage current; so that, other things being equal, the closer the pipe is to the rail the greater will be the induced effect, which is rather different from tramway practice.

With regard to the question of earth currents, I do not think we need trouble about them very much, thanks to the modern telephone lines, which all have double circuits. But there is one little point I have suggested to the engineers of this railway. Ordinary telegraph instruments would not respond to alternating earth currents, but a Wheatstone automatic, running at 400 words per minute, might pick it up, and the result might be rather awkward. Political speeches are transmitted by these instruments, and a succession of nothing but dot, dot, dot would mean "I," "I," "I"!

The impedance of the rails, of course, will concern this matter. I learned the other day at Berlin that on the Spindersfeld line the total impedance of the rails, measured as ordinary ohms, is only half an ohm per kilometre, with a 25 periodicity. That seems to be better than some of the Swiss lines.

There is only one more point to which I should like to refer. The author mentions the great disadvantage of the compartment type of car, and says that when the trains are well filled time is lost by intending passengers seeking compartments. I saw the other day a very interesting type of carriage, which is extensively used in the suburban service of Berlin, and I believe it has commended itself favourably to certain English railway engineers. Take an ordinary carriage, seating five a side, and a partition at the back; you could alter it into the type to which I refer with a saw. You cut through the partition and the seat, making a passage of 18 inches, and sacrifice one seat. You retain the ordinary doors; the passengers get in anywhere, and pass through this 18-inch gap quite easily. There are just as many doors as in the ordinary rolling stock, and it works very well indeed, and I should think it is a type which should commend itself very favourably to the public in comparison with the end-door carriages which have been forced upon them recently.



Discussion at Meeting of February 8, 1906.

Mr. Schoepf. Mr. T. H. Schoepf: In reading Mr. Carter's paper I was rather struck by the analytical method which he advances for working up the train curves. I have had to work up many hundreds of these curves, and have always adhered to the point by point method as the more accurate of the two, and do not agree with Mr. Carter in his conclusion that the analytical method is sufficiently accurate and less laborious. I think he will admit that in case he were called upon to make a guarantee as to the schedule speed to be maintained and energy

consumption, he would abandon the analytical method in favour of the point by point method. The analytical method gives one a guide as to the adaptability of a motor with given characteristics to the requirements of the scheme under consideration, but gives no certain information leading one to say definitely that the motor is of sufficient capacity to do the work required; and if it is not known whether the motor is of sufficient capacity, then one must refer to the point by point method to determine the square root of the mean square current and the average voltages which determine the copper and iron losses respectively, and the analytical method is, in my opinion, simply a rough approximation. Mr. Schoepf.

In discussing this paper I wish to deal particularly with the comments made on the single-phase system, as the author's statements and conclusions are so novel and contrary to the experience of practically all engineers who are directly responsible for the development and application of such equipments.

On page 233 he states that the weight to be added to that of the train because of the inertia of the rotating parts is 8 per cent. in the case of continuous-current equipments, and it may be double this value for single-phase equipments. My experience leads me to draw a conclusion differing from the opinion expressed by the author. I have personally calculated this factor in comparing continuous-current and single-phase equipments of equal capacity for projected schemes, and under normal conditions I would add 10 to 12 per cent. for continuous-current equipments and 12 to 15 per cent. for single-phase equipments. Of course, the dead weight and composition of the train exercise an influence on this factor, and it cannot be decided arbitrarily. Let us take under consideration two such equipments. Firstly, the continuous-current equipments supplied to the Metropolitan Railway: the value taken was 12·1 per cent. from the actual calculation of the rotating parts, and I would use 14·5 per cent. for suburban trains on the London, Brighton, and South Coast Railway. In each of these cases the motor-coach equipment comprises four 150-H.P. motors. In considering this subject one must not compare the above factors alone, as the train on the Metropolitan Railway weighs 160 tons, and the train proposed for the L.B. & S.C.R. will weigh approximately 105 tons. After correcting the above factors for this difference you will see that the percentage of the weight to be added is practically the same.

On page 252 Mr. Carter states that if the earth currents due to leakage from the return circuit are to be reduced to the same order as found for direct-current operation, it will be necessary either to have track boosters or work with a voltage of at least 6,000 volts on the trolley, and under these circumstances he maintains that the distance apart of the substations will only be the same as for direct-current operation.

Taking into account the fact that pipe work, usually of iron, in the surrounding soil has induced in it a counter E.M.F., the actual destructive electrolytic current will be very small, and it is found

Mr. Schoepf. quite sufficient to take the ohmic drop in the rail as being the effective volts drop in the return circuit. Hence, with the higher alternating-current voltages the substations may be placed very much further apart in alternating-current operation than they could possibly be for direct current.

As regards the destructive effect from the electrolytic action of alternating current, I have discussed this matter with Mr. Kintner, who very carefully conducted a series of tests. He stated that the results showed that this was practically nil, and for a report on these tests I would refer you to the *Electric Journal* of November, 1905, and I am quite convinced that when using the rail properly bonded with drops of 60 to 100 volts, it will prove to be quite harmless.

The author states that in order to overcome some of the objections to single-phase working, energy will have to be supplied to the trolley at 6,000 volts, and I may say that the Westinghouse Company of America have undertaken and are executing a contract for the New York, New Haven and Hartford Railway for 11,000 volts to be used on the trolley. I have no hesitation in saying that no serious difficulties will be encountered with trolley voltages as high as 20,000. The Swedish State Railways are now conducting experiments on a suburban line operating at this latter voltage.

From tests which I have personally made, and from the result of tests which other engineers have carried out, I am quite convinced that there is no necessity whatever for a booster system where reasonable drops in the track circuit are considered.

The author is, in my opinion, quite wrong in his conclusion that the single-phase system is not in general suited for urban and suburban work on railways, and in replying to his statements supporting this conclusion, I may say that the range of power of the motor is not a very important one, and it is of no particular advantage to either system, since either motor should be designed specially for urban or suburban working, or for high speed long distance work, and if such a motor is designed for either class of service it is not as economically applicable to the other class.

Regarding the comparative efficiency of the two systems, I can but confirm what Mr. Dawson has so ably expressed.

The author states that the single-phase motor is heavier than a continuous-current motor of equal capacity, and I may say, as an example, that the Westinghouse single-phase motor of 150-H.P. capacity weighs 5,398 lbs., and a similar continuous-current motor of equal capacity weighs 5,550 lbs., which proportion is practically the same throughout the range of their traction motors.

When comparing these two types of motors at their normal full-load capacities, it may be of interest to know the respective basis of the rating. In the case of the single-phase motor, the rating of 150 H.P. is the B.H.P. which this motor will develop for one hour when supplied with alternating-current power at 25 periods, 250 volts across the motor terminals, and a motor current of 630 amperes, with a power factor of 83·5 per cent. Under these conditions the rise of tempera-

ture of the motor does not exceed 75° C. above the surrounding air. In the case of the continuous-current motor, the rating of 150 H.P. is the B.H.P. which this motor will develop for one hour when supplied with continuous-current power, 550 volts across the motor terminals, and a motor current of 234 amperes. Under these conditions the rise of temperature of the motor does not exceed 75° C. above the surrounding air. Mr. Schoepf.

I should like to ask the author on what he bases the statement that a single-phase railway motor with a given outside shell has little more than half the service capacity of the continuous-current motor having a similar shell, as I may state most emphatically that this is an error when considering the series type of motor.

The author states that the alternating-current equipment is considerably heavier than the corresponding continuous-current equipment, and I may say that a single-phase equipment suitable for the suburban working on the London, Brighton, and South Coast Railway will not weigh more than 31,000 lbs., which includes the entire electrical equipment; and the weight of the electrical equipment of one of the motor-coaches of the Metropolitan Railway is 29,500 lbs., so that you may see that there is not a considerable difference, as stated by the author.

The author states that the car bodies will be heavier in case of single-phase than in that of direct current, as the under-framing needs to be stronger. I have had to consider and design the hangers for the apparatus for both types, and cannot possibly find any difference in the two. If the author will consider the design of car under-frames, and the high safety factor demanded, he will find that if the extra weight of 2,000 lbs., which is approximately that of an auto-transformer, were applied at the very middle of the car, where the strain set up would be greatest, he will probably be relieved of uneasiness on this score.

The author has referred to equipments which are in operation on the Indianapolis and Cincinnati Railway, and, while I think it does not bear on the subject, as he has discussed the application of single-phase to main line working with multiple unit trains, it may interest the members to know that these cars are of special design, seating eight passengers more than the average interurban car, having two passenger compartments, a lavatory, parcels space, and luggage compartment. The distance between truck centres is greater than in the average interurban car, and therefore the under-frame is necessarily heavier. The equipments are designed to work at three trolley voltages, namely, 550 and 3,300 alternating current, and 550 continuous current, which conditions, of necessity, increase the weight. As a matter of fact I know the weight of car body, under-frame, and trucks is about 68,000 lbs.

Mr. H. M. Hobart: For main line working high tension is absolutely necessary. For high tension it seems to me that an overhead construction is also necessary. The overhead construction has been well worked out for the single-phase system. But when we come to the question of the motors, we are under a great disadvantage with the Mr. Hobart.

Mr. Hobart. single-phase system. Why not use the good feature of the single-phase system, namely, the overhead construction for high voltage, and a high voltage continuous-current motor? That it has not been used to a greater extent heretofore is largely owing to misconceptions. In designing dynamos for generating stations we have ample space at our disposal. In designing dynamos for increasing capacity we find we can get better commutator results by increasing the armature diameter and having more poles; and a consequence of this is that we find we can get better commutating results with a reasonable voltage, say 550. But the problem of railway motor design is considerably different. There we have an exceedingly restricted space as regards both diameter and length parallel to the shaft; and as we go to increasing capacities we can actually get better results as regards commutation the higher the voltage; so that whereas some 600 volts may have been a most favourable voltage as regards commutation for motors of 30 or 40 H.P., such as were used up till recently in light tramway work, we actually get better commutating results by increasing the commutator voltage with increasing rated capacity. When we come to main line working we require motors of a capacity of anything from 150 H.P. upwards per axle, often running up to 300 and 400 H.P. per axle, and it is absolutely important to keep them as compact as ever we can. Therefore we are restricted to a small diameter. With a given diameter the problem is altogether changed. In dynamo design we increase the diameter with increasing output. We cannot do that in a railway motor. Any one who has the slightest acquaintance with the calculation of the commutating properties of motors will find, on looking into it, that, with a fixed diameter, one is absolutely aided in getting good commutation, with larger rated capacities, by taking higher voltages. A failure to recognise this point has been the chief obstacle to raising the commutator voltage of continuous-current traction motors. As soon as misconceptions on this point are eliminated, the way stands clear for high-voltage continuous-current traction; and I think that a very small part of the money which has been spent in developing the single-phase motor up to its present state—which still is considerably wanting when it is subjected to a strict comparison with continuous-current motors—would result in a highly satisfactory continuous-current high-voltage motor, and I trust that manufacturers and railway engineers will give this matter their careful consideration.

Mr. Jenkin. Mr. C. F. JENKIN: Mr. Dawson at the last meeting spoke almost entirely about the compensated repulsion motor, and I should like to mention a few points in connection with the compensated series motor, upon which Mr. Schoepf has not touched. I can confirm in general all the statements Mr. Dawson has made: they are really equally applicable, speaking generally, to either sort of motor. Turning to page 254, the author says that the range of power is more limited with an alternating-current motor than with a continuous-current motor. As a matter of fact, in laying out a motor for a given service one does not come across any limitation owing to this range of power, and therefore the fact that the theoretical range of power is less in the one case than in the other is no

detriment to the motor. A little further down on the same page the author says that the alternating-current motor has a less favourable speed torque characteristic. That, I think, is entirely a misapprehension. If you refer to the characteristic curves given for the two motors, you will see that the single-phase curve falls to the left of the continuous-current curve; that is to say that, for a given tractive effort, the speed of the alternating-current motor is lower; in other words, the motor is rather more self-regulating than the continuous-current motor. Mr. Jenkin.

The ideally unsatisfactory characteristic curve, that of the shunt continuous-current motor, would be represented approximately by a vertical line in the diagram; the motor would run to a constant speed for all torques. Comparing the other two curves with that imaginary straight line, it will be seen that the advantage which the series motor has over the shunt motor is indicated by its curve falling to the left of the straight line; the alternating-current motor curve falls still more to the left. To put it in another way, the only difference between the single-phase curve and the continuous-current curve is that the single-phase machine is more self-regulating: or, to put it in a third way, you need only keep your starting resistances in circuit up to a lower speed with the alternating-current motor than you have to with the series motor, which, of course, is again a very much lower speed than the corresponding speed of a shunt motor. The fact, therefore, that the curve for the alternating current lies to the left of the other curve is an advantage and not a disadvantage. The author a little further on refers to the lower efficiency of the alternating-current motor. The figures have been published for the motors used on the Oerlikon line. They are 200-H.P. motors, and at full load the efficiency is 92 per cent. This really does not seem to leave very much to be desired. These motors are designed in the same way as those with which I am familiar, with commutating poles between the main poles, which gives a decided advantage. It enables good commutation to be obtained without the use of resistances, or with only very small resistances in circuit with the armature coils, and so saves loss there. Mr. Dawson's statements with regard to the weights and so on were, I think, quite fair, though a little too favourable for the alternating-current motor. On the line which the Siemens-Schuckertwerke built at Murnau, which was the first line in the world to be worked with compensated series motors, and was working and open to the public before any line in America, certain calculations were made before the single-phase system was adopted. The line was already partly equipped, when it was taken over by the Siemens-Schuckertwerke, on the 3-phase system, and it became necessary to ascertain whether it should be completed on that system or on some other system. Three complete calculations were therefore got out, for continuous current, 3-phase current, and single-phase current, and the results are as follows:—The efficiencies of the systems, reckoned from the bus-bars to the tyres of the wheels, were, for the 3-phase, 66 per cent., for continuous current, 62 per cent., and for single-phase, 71 per cent. For the same systems, the cost of installa-

Mr. Jenkin. tion, including the cost of equipping the line and the equipment of the cars, worked out in these ratios: for the 3-phase, 116; for the continuous current, 125; for the single-phase, 100. You will see, therefore, that the single-phase is 16 or 25 per cent. cheaper, and 5 or 9 per cent. higher in efficiency than the other systems. This shows, I think, that at any rate in some cases the single-phase is very much in the running. These figures must not, of course, be understood as in any way applicable to general cases; they are only the particular figures for a particular line. Mr. Dawson made one statement about the advantages of single-phase motors which I do not think can be upheld. He stated that the acceleration curve can be made to go up straight from the start, or from just after start, up to the maximum speed; that is to say, you could have practically a uniform acceleration right up to the full speed. That certainly can be done, but it seems to me inevitably to involve a larger maximum load on the motor. The maximum load on the motor occurs where the straight part of the acceleration line finishes and begins to go off on to the characteristic curve. If you take that point right up to the full speed, it inevitably means a higher maximum load on the motor, and therefore I do not think you can make use of that method of starting on a railway. Owing to the method of control, you could raise the voltage while you are accelerating to a higher value than you would afterwards use when you were running at full speed. That would enable you to get the form of the acceleration curve mentioned by Mr. Dawson, but it would involve this extra load on the motor, and is not, therefore, really available.

Mr. McMahon. Mr. P. V. McMahon: The first speaker in the discussion raised the question of single-phase motors versus continuous-current motors, and dealt with the matter so fully that I can add nothing further unless to say that I entirely agree with him that, all things considered, the single-phase system is better than the 3-phase with conversion to continuous current for heavy urban and suburban traction. He next referred to the question of substation efficiency. The author gives 78 per cent. as the maximum efficiency which could be obtained in a continuous-current substation, and Mr. Dawson gave 74 to 75 per cent. By that I take it he means 3-phase, transforming to the continuous current, at the third rail. In the simple continuous-current 3-wire system, with substations, fed at 2,000 volts across the outers and 500 volts at the working conductor, as we have on the City and South London Railway, the efficiency of a substation $2\frac{3}{4}$ miles from the generating station is 86 per cent., including cable losses between the generating station bus-bars and the locomotive; in another substation $5\frac{1}{4}$ miles from the generating station it is 81 per cent., and the efficiency for the whole line between the generating station bus-bars and the locomotive is 90 per cent. I do not advocate a system of this sort for such heavy urban or suburban work as is contemplated in the London, Brighton, and South Coast electrification, but at the same time I do not see why advantage should not be taken of the 3-wire method of distribution combined with the single-phase system. In this way, it

seems to me, a good deal of the rail drop would be got over, that is to say, it would be possible to use a very much higher current density per mile of tract, or a greater train density, without increased rail drop and the consequent trouble with pipes, etc. The question of balancing might naturally arise. Some years ago most traction people would have told you that it was impossible to use the 3-wire system for traction at all, but five years' experience and actual working of that system has shown us that there is absolutely no difficulty at all in balancing. We went to some trouble in the beginning to install large balancers, but now the traffic itself balances so well that we do not use the balancers. This remark applies equally no matter how heavy the service, so long as it is fairly regular. A good deal has been said about the third rail, and it seems to me to be too generally condemned. I do not see why it should be so condemned, because I think it has many advantages over the overhead or the third and fourth rail systems. If the overhead system is properly constructed it is perhaps preferable, but it must add considerably to the cost as compared with the ordinary third rail. I do not see that it is any more difficult to arrange a third rail over points and crossings on a main line than in tunnel railways. The points are just as complicated in cross-over roads in tunnel railways as on the main line, but there are not so many. With voltages above 600, it is perhaps inadvisable to use the third rail. Another point put forward against the third rail is the danger to the workmen on the line. I think that is merely a question of education of the workmen; they soon learn how to keep clear of it; in fact, during the fifteen years in which we have been working with 500 volts we have never had any cases of accidents to workmen due to the 500-volt third rail. An elevated third and fourth rail, that is, a third rail in the centre and the fourth rail forming an insulated return on the side of the track, seems to me to be absolutely debarred from main line practice, because I do not see how you can possibly arrange the fourth rail at complicated points and crossings, especially if a locomotive is used. With a motor car the shoes, or collectors, at each end give a longer distance between the collecting points, and this reduces the difficulty somewhat, but with the locomotive, which is much shorter, I do not think it is possible to use the fourth. Mr. McMahon.

Mr. W. M. MORDEY: In the opening of this paper the author raises our hopes by deprecating generalisation, and by expressing his determination to attack the technical engineering problem in a strictly logical manner. That being so, I felt sure I should find him in agreement with the conclusions I had come to! But I received a check a little further on in his reference to people who had written without a grasp of the conditions, and had given railway people misleading ideas, particularly those who had written on single-phase working. I read with great humility and a desire to learn—my desire for truth was uppermost. Well, the author comes to two main conclusions. One, condemnation of single-phase working; the other, hopelessness as to main line railway electrification. He has my sympathy. Logically—and he is above all things logical—if he condemns single-phase work- Mr. Mordey.

Mr. Mordey. ing, he must be hopeless about main line electrification. We must deal very severely with anyone who is going to prove that it is impossible or improper to work railways electrically! I think Demetrius the Silversmith expressed our views on such doctrines. They are dangerous to our craft! But, seriously, I am sorry the author, evidently after very careful consideration, has come to conclusions which are opposed to those arrived at by many engineers who have thought and worked on this subject. The paper amounts to a contribution to the battle of the systems. What is the system of the future going to be? The author condemns single-phase working because three or four years have been devoted to it, and he thinks nothing more is to be hoped for from it. Are the results with direct current, after twenty years of effort and experience, such as to satisfy us? The author thinks they are. He is convinced, for example, that nothing can be more effective and economical than the Liverpool-Southport direct-current electrification. It is not direct-current to begin with. It is alternate current up to the substations. What is this economical operation, and what is this effective operation—remembering that effectiveness includes safety?

On the few miles of new railways recently started—Liverpool-Southport, Newcastle, District—they killed eighteen people by shock in the year 1904–1905. High-tension overhead work could not be much less safe than this low-tension track work. Mr. McMahon says he has had no fatality in fifteen years. He is to be congratulated, but his tunnel conditions are very different from ordinary open railway conditions. But what is this vaunted direct-current efficiency? The author condemns single-phase mainly because of the lower efficiency of the motors (page 254), and shows us in Fig. 2 that the efficiency of direct-current train motors is very high—nearly 90 per cent. through a large range of output—but is he quite logical? Do not his own figures show that motor efficiency has very little indeed to do with train efficiency? Let us examine the direct-current efficiency. Consider the author's Fig. 7 and see how little that figure would be affected if the motors were 80 instead of 90 per cent. Fig. 7 gives the train losses only. What happens before the energy gets to the train is another matter. Take, for instance, the vertical speed line in the diagram at 36 miles. You will see the train resistance, which is the real thing, takes only 16·6 per cent. of the energy that reaches the train, the braking takes 53·5 per cent., the starting resistance 17·8 per cent., or more than the train resistance, the motor and gear losses 13 per cent., or nearly as much as the driving of the train. Put briefly, the 90 per cent. motor gives a locomotive efficiency of 16·6 per cent. This diagram proves, to my mind, that for the very purpose for which the direct-current system is specially claimed to be good, namely, suburban or town traffic, with fairly high average speed and frequent stops, it is, from the energy point of view, about as bad as it can be.

I am very glad to see this Fig. 7—it confirms what I have often pointed out,* but have never seen elsewhere recognised: the very poor

* *Electrical Magazine*, pp. 45, 266, 477, 577, 1904.

results shown by direct-current locomotives under the conditions of town lines. **Mr. Mordey**

To illustrate this point further, I may perhaps be allowed to refer to two examples of direct-current work—Liverpool Overhead and Central London. At Liverpool they boast (and rightly) of a very high acceleration. It is a typical town line, with many stops and a good, high average speed. Of the energy that reaches the train, the actual driving takes 21 per cent., the brakes absorb 50 per cent., and the motors, gearing, and starting resistance 29 per cent. How are these losses to be reduced? A great English engineer, Mr. Greathead, saw one way of doing that, and as a result, on the Central London, each station was put on the top of a little hill, the train being braked by storing up energy going up the hill, and being started down hill with the help of that stored-up energy. The result is that the locomotive efficiency on the Central London Railway is more than twice as high as on the Liverpool line. But even then, the braking and starting resistances each take about 23 per cent. of the energy that gets to the train. There is no important difference between the two cases so far as the direct-current train equipment is concerned. This shows how motor efficiency may be relatively unimportant.

I think single-phase motors, taken by themselves, are, and always will be, of lower efficiency than direct-current motors. The difference will probably be 10 per cent. But that difference may be relatively unimportant—it is the efficiency of the whole system that has to be considered, not of one bit of it. There is not time to go into this now. The author, however, at page 250, admits a gain, for alternate current, in transmission to the train of 9 per cent., which should about balance the loss in the motor. And there are other gains that are more easily attainable by alternate than by direct current.

Further on the author says that with alternate current both power and energy must be 30 per cent. higher, that is to say, the peak must be higher, as well as the units generated. Why must they be higher? Is it a law of nature? Is there nothing in what we have all been believing, that it is better to regulate by a back E.M.F. than by a wasteful resistance? The direct current peak is at starting on these short suburban lines. What can be done with alternate current to reduce the drain on the station at starting? I made a test some time ago with a 50-period, 1-phase alternate-current, 15,000-volt locomotive, with this result. We got about 134 per cent. of full-load torque, with only about 38 per cent. of full-load primary current. I do not know what the power factor was, but taking it at unity, if you like, that means the difference between direct current and alternate current would be as four to one (or two to one, according to the arrangement of motors) in the load on the generating station. So that instead of 30 per cent. more, it was 50 per cent. less. But remember, to get this kind of effect, we must adopt variable ratio transformation and back E.M.F. regulation, and we can only get those by alternate current. There is a very great deal to be said for alternate-current working, not only for long lines but, I would say, especially for short and busy lines.

Mr. Mordey. The author says, on page 254, that 1-phase equipment is two to two and a half times as heavy as direct current equipment, and that the train will be 30 to 40 per cent. heavier. He quotes two examples, in one of which it is 21·6 per cent. heavier. But, granted it is heavier—and I think it will be a little heavier—does he not remove his own objection by stating, pages 233 and 234, that for main line high-speed long-distance work, weight is of secondary importance; that it only accounts for two and a half to three and a half out of the total of 13 lbs. to 15 lbs. per ton train resistance? The author refers (page 252)—this is not a matter of principle, but I may perhaps allude to it—to the question of rail boosting. I would object that the arrangement he shows is one that forces the return current into the rails. The object of a booster, I think, should be to get the current out of the rail.

Four years ago, Mr. Bernard Jenkin and I read a paper on electric traction on railways at the Institution of Civil Engineers.* Nobody at that time believed in 1-phase working. At the end of the discussion I said we were prepared to wait ten years for 1-phase working, which we felt must come. We argued in this sort of way. We must have overhead wires for open country work, therefore we must have high tension. If we have high tension we must have alternate current. For reduction of voltage at frequent intervals we must have static transformers—rotaries would be hopeless; that again means alternate current. We must have variable ratio transformation and control if we are going to work economically; that also means alternate current. We must, or we should, have a variable E.M.F., so as to use high tension outside and low tension in the tunnels or in the stations; that means alternate current again. And we must have overhead line simplicity—we must approximate to the simplicity of the ordinary trolley system—and that brings us to 1-phase and to a method suitable for either long or short lines, without break of electrical gauge. Our argument may have been wrong; anyhow, that is how we argued. Since then the alternate-current commutator motor has been developed, which can work either with alternate or direct current, greatly simplifying the break-of-gauge question. But even at that time we were not without a quite good and practical method of 1-phase driving. One word in conclusion: Logic is a very dangerous thing. I was studying "Jevons on Logic" at the time of the Tichborne case. When I found that Professor Jevons was a strong advocate of the claimant, I closed the book and have never read any logic book since.

Mr. Carter. Mr. F. W. Carter (*in reply*): In writing this paper I had no intention of raising a discussion on the single-phase as opposed to the continuous-current system of operation, and I hope Mr. Mordey and others will read the paper again and realise that on the one hand I have referred to sundry other matters, and on the other that I have by no means condemned the single-phase system altogether. All I have said against it amounts to the statement that in severe suburban service it compares very unfavourably with the continuous-current system. I see no reason for changing that conclusion.

* *Minutes of Proc. of Institution of Civil Engineers*, vol. cxlix. p. 40.

Mr. Dawson spoke at length on my paper, and if I reply to him pretty fully I expect I shall cover most of the points which have been subsequently raised. On one or two points Mr. Dawson has misunderstood me. He refers to a statement of mine on page 252 concerning power factor, and claims that the power factor in the single-phase system is quite as high as in the continuous-current system. I do not admit his claim, but would state that I have said nothing on the subject. My reference to power factor is in connection with the voltage drop in the track rails, in which we are only concerned with the power factor of the current supplied to the motors. This is of course unity in the case of continuous-current motors, and less than unity for single-phase motors. Again, Mr. Dawson claims to have found somewhere a statement of mine to the effect that the multiple-unit system of control cannot be used with single-phase motors. I have made no such statement, as I know well enough not only that it can, but that it is even simpler than in the continuous-current system, on account of the series-parallel combinations being absent. Mr. Carter.

It seems to have been inferred by Mr. Dawson that in speaking of the alternating-current motor I am referring to some particular type which is not the best. I may say that anything I have said is intended to apply quite as much to the particular motor in which he is interested as to any other motor, and anything I have to say now he may take as intended to apply particularly to this type of motor.

Exception is taken by Mr. Dawson to my statement that the equipment losses are usually quite as great in the single-phase as in the continuous-current system, in spite of the large rheostat losses in the latter system. He claims that the motors with which he is acquainted have only about 4 per cent. lower efficiency than the very best continuous-current motors. I believe Mr. Dawson is mistaken in this, but even if it were the case at the most efficient load and on the most efficient tap of the compensating transformer, the average is certainly much worse. I was not referring especially to the efficiency at a particular point, but to the overall efficiency in service, and Mr. Dawson has supplied us with figures which I think will be sufficient to prove all I would desire. In connection with a comparison of single-phase and continuous-current equipments for the same service, he gave the equipment efficiencies as 74·2 per cent. and 73·6 per cent. respectively (see Fig. B). That is to say, out of 100 parts of energy supplied, 74·2 are delivered to the driving-wheels in the single-phase system, and 25·8 are lost before reaching the driving-wheels; similarly in the continuous-current system 26·4 parts would be lost. There is therefore only a difference of 0·6 parts loss in the two cases, in spite of the fact that the continuous-current case includes a great deal too much rheostat loss, as I shall show hereafter. I therefore adhere to the statement on page 235, and consider that Mr. Dawson's figures prove it.

In stating that the single-phase motor is rated on the same basis as the continuous-current motor Mr. Dawson is in error; it is not. If the 115-H.P. motor he has referred to were run for one hour, giving an output of 115 H.P. through the gears, the temperature

Mr. Carter. rise of the armature would exceed 90° C., and somewhat less than 90 H.P. can be obtained through the gears if the temperature rise is to be limited to 75° C., as required in the standard method of rating.

This motor therefore, of which the commercial rating is 115 H.P., rates at 90 H.P. on the same basis as continuous-current motors, whilst its weight is correctly given by Mr. Dawson as 2·4 tons, including pinion. Now a certain continuous-current motor, which is in common use to-day on the Boston Elevated Railway, rates according to the same rule at 175 H.P., and weighs 2·15 tons, including pinion. The weight per horse-power on the same basis of rating is therefore more than twice as great in single-phase as in continuous-current motors.

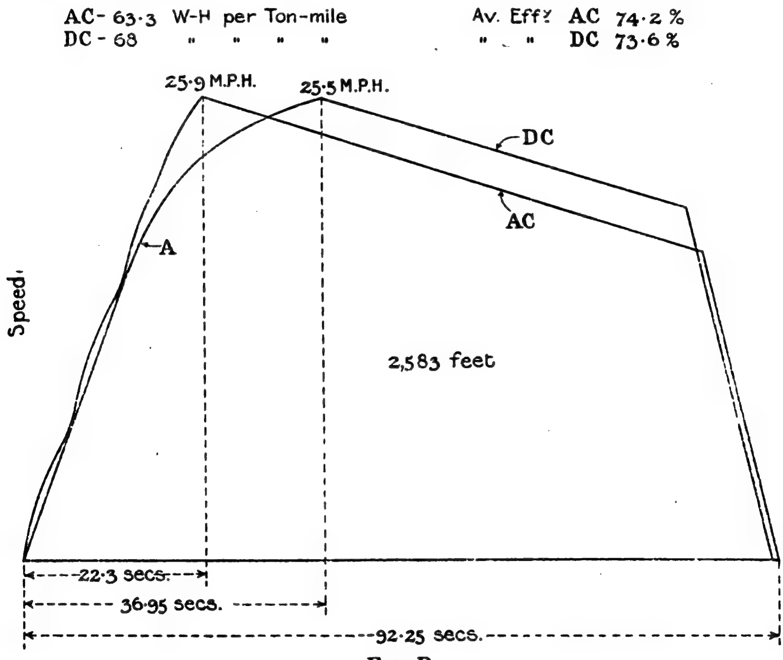


FIG. B.

Mr. Dawson gave what were supposed to be comparative figures of single-phase and continuous-current operation for a particular run of 2,583 ft. I recognised the figures as having been given, together with some curves, in some of the technical papers about the middle of November last. I observed at the time that the curves and figures were in no sense a comparison of the two systems, but merely an effort to discredit the continuous-current system. I have reproduced the curves in the diagram herewith (Fig. B), in order to show what sort of thing is intended, although I shall really only use Mr. Dawson's figures. Now, I want to show you that these curves and figures have been got up with the special idea of showing the worst features of the

continuous-current motor, and are not in any way representative of practice. Mr. Carter.

The first thing noticeable is that the continuous-current motors are quite unsuitable for the service that they are put to do, and are not employed in their normal manner. The rate of acceleration has been kept down, in order to be below that of the single-phase motor, and to make the period of rheostat running as long as possible. The low rate of acceleration and the large amount of rheostat running both tend towards making an artificially high energy consumption and a low equipment efficiency. Up to the point marked A the loss of energy in rheostats is almost exactly 30 per cent. of the total input to that point, and the loss in the motors and gears is about 12 per cent. Therefore the efficiency up to the point A is about 58 per cent. If coasting is started at this point a very unfavourable condition for the continuous-current motor would be obtained, but of course the curve would not look very much like a continuous-current train characteristic; accordingly a little speed-curve running is introduced, but only just as little as will pass muster. From dynamical considerations it appears that the total amount of energy lost in the rheostats is in this case at least 15 per cent. of the whole input.

And now I would like to show you something else in connection with these comparative figures of Mr. Dawson. This is that, in order that the single-phase equipment may not appear disproportionately large, much greater continuous-current capacity than single-phase capacity has been included in the equipment. I, of course, have other sources of information, but as these matters are subject to the ordinary laws of physics, I propose to deduce all I require from Mr. Dawson's figures. I have referred above to the equipment losses in this comparison. Of the 26·4 per cent. loss in the continuous-current equipment, at least 15 per cent. is lost in rheostats, 5 per cent. in gears, and not more than 6·4 per cent. in motors. Of the 25·8 per cent. loss in the single-phase equipment, perhaps 3 per cent. is lost in transformers, 5 per cent. in gears, and 17·8 per cent. in motors.

As the input per train mile will probably be greater in the latter system (in spite of the lower input per ton-mile), the loss per motor cannot be much less than three times as great in the single-phase as in the continuous-current motors. Although the former motors are larger, they will be unable to dissipate more than 20 per cent. or 25 per cent. more heat than the latter with the same internal temperature. It follows that the temperature rise in service would be very different in the two cases, and either the single-phase motors could not do the service continuously or the continuous-current motors could do a considerably more severe service. As a matter of fact both these conclusions are correct. The single-phase motors are over-run to show their dynamical capability, and the continuous-current motors are under-run, as the eight motors are more than are required to propel the train. Mr. Dawson's comparison is therefore ridiculous as a comparison of operation and worthless as a comparison of dynamical capability.

Mr. Carter. There is another point which Mr. Dawson raised which is quite a fallacy, as was pointed out by Mr. Jenkin. Mr. Dawson claimed as a disadvantage of the continuous-current motor that the acceleration, although keeping fairly high up to a certain point (the point A in Fig. B), begins to fall off and gets slower and slower during speed-curve running, whilst the alternating-current motor can be made to keep up a high rate of acceleration to the highest speed. To take advantage of this, however, as Mr. Jenkin pointed out, would be very foolish, as such a procedure results in a much higher peak of power than obtains if the rate of acceleration is allowed to diminish as high speeds are reached.

This is merely a question of dynamics, and has nothing at all to do with the type of motor. The tractive effort multiplied by the speed is proportional to the power output. Now, the tractive effort is practically determined by the rate of acceleration. This is about the same in the two curves of Fig. B, but whilst in the continuous-current curve it is maintained at its highest value only up to the point A, where the power output reaches its highest peak, in the single-phase curve it is continued to the highest speed, which is about 50 per cent. higher than at the point A, and therefore represents a 50 per cent. higher peak of power.

The peak of power, compared with the average, is bad enough in the continuous-current system, and no engineer would wish to make it worse. Taking a concrete example, on the Central London Railway the energy consumption has been found to be 42 watt-hours per ton mile, the schedule speed is 14·7 m.p.h., and the weight of the train is 125 tons. The average power taken by a train is accordingly 77 k.w. The maximum peak of power occurs when the four motors are each taking their accelerating current of 200 amperes at 550 volts, being then 440 k.w. The ratio of the maximum to the average input is accordingly 5·7. Mr. Dawson would have this ratio increased to 8 or 9, and, in fact, in the particular case of the single-phase curve in Fig. B, it is approximately 9. From an operative point of view the advantages to be gained from the little longer continued acceleration are much more than counterbalanced by the disadvantage of having this very high peak of power.

The one point that Mr. Dawson rather evaded is that of cost, and provided both systems can be made satisfactory at some cost, this is ultimately the only point of importance. Anyone in a position to investigate the subject of suburban service will ascertain that the cost is altogether very much higher for the alternating-current than for the continuous-current system. In long distance service it is probable that the position would be reversed. For main line service undoubtedly the cost of the alternating-current system would be lower than that of the continuous-current system, but in the case of suburban service I cannot see in the least that it can be other than considerably higher both in installation and operation.

Mr. Dawson has mentioned the extra cost of the substations, and if there were nothing but the substations to consider, one could make an irresistible case for the alternating-current system. Not so, however,

if the system is considered as a whole—the line conductors, the train equipments, the generating plant, as well as the substations. Mr. Carter.

Whilst thanking Mr. Dawson for the good opinion he has expressed of my paper, I would state that I see no reason to modify the conclusions I have expressed.

It may be asked why certain continental installations on the single-phase system are apparently satisfactory. I believe the explanation lies in the fact that the schedule speeds are lower, considering the frequency of stops. That is to say, they do not come under the heading of severe-service railways, and are covered by the statements in the second paragraph on page 256 of the paper.

Mr. Schoepf objects to the analytic method of treating train characteristics. This, however, has nothing to do with the present paper, and I am indifferent as to whether Mr. Schoepf uses my methods or not. He objects to my statement concerning rotary inertia, and says he has found it only about 12 per cent. of the weight of the train in the single-phase system. He does not state what class of service he refers to, but for multiple-unit trains in suburban service I have usually found it 16 to 18 per cent. of the weight. It, however, is not a matter of great importance, and, as Mr. Schoepf pointed out, is not properly expressed as a percentage of the weight. Mr. Schoepf claims that there is practically no electrolysis with alternating currents and considers 60 or 100 volts drop in the rail of no consequence. Mr. Trotter, on the other hand, finds the electrolytic corrosion about half as much as with continuous currents and considers 20 volts drop reasonable. I prefer to believe Mr. Trotter. Mr. Schoepf gives comparative weights of 150-H.P. continuous-current and single-phase motors, and claims an even better weight efficiency for the latter than for the former. This would certainly not be found the case in service. The commercial rating of a new type of motor is, however, quite an arbitrary matter, and the weight efficiency of the motor in question would be in no way improved for service purposes if it were called a 200-H.P. motor. I have no reason to believe that the motor in which Mr. Schoepf is interested is superior in weight efficiency to that referred to by Mr. Dawson. It is of no use to give us the weight of a motor coach equipped with motors of a certain rating, as Mr. Schoepf has done, or of a pair of motor bogies, such as Mr. Dawson has given us, without at the same time stating what service they are capable of. Continuous-current and single-phase motors act differently in different classes of service, and are not comparable the one with the other, even if they were rated on the same basis.

As to what Mr. Mordey has said, I can agree with much of it, but would point out that my paper is not opposed to it. My objections to the single-phase system apply to its use for suburban service, and most of the objections I have raised would have little weight if applied to main line working.

Communicated.—One or two other matters were brought up by Mr. Dawson which may cause misapprehension if not referred to. He considers that the figure of 78 per cent. given in the

Mr. Carter. paper for the overall efficiency from generating station bus-bars to trains in the continuous-current systems is over-estimated, and suggests 74 or 75 per cent. as being more probable. For a modern heavy railway system, 78 per cent. is a very conservative figure, and 80 per cent. would not be unduly high. Possibly the figures he suggests obtain in tramway systems. Mr. Dawson refers to the capital cost of low-tension feeders and speaks of this large expenditure as being due to the use of continuous-current motors. The same objection has been raised against the continuous-current system by other advocates of universal single-phase working, and I have hitherto explained it as due to ignorance of railway practice and pardonable confusion with tramway practice on the part of persons not very conversant with the subject. But, the subject being one with which Mr. Dawson is very familiar, he is doubtless aware that the low-tension feeders are run from the substations directly to the third rails immediately outside the substations, and are not run to distant sections, as in tramway practice. The length of the low-tension feeders being a matter of yards only, it is difficult to see that their cost can be a serious item, or that it can be appreciably reduced in the single-phase system. There is, therefore, evidently some misapprehension, and I should feel personally obliged to Mr. Dawson if he would take an opportunity of explaining it.

I should like to thank Mr. Trotter for the information he has given concerning the electrolytic corrosion to be expected with alternating earth currents. There is usually less danger of electrolysis from railways than from tramways, on account of the rails being fairly insulated and at some distance from parallel pipes, and I am pleased to observe that Mr. Trotter recognises this fact, and is apparently prepared to allow greater latitude to railways in the matter of voltage drop, where the conditions appear to warrant it.

The views of Mr. Hobart on design are always illuminating, and I am pleased to find him sanguine concerning the success of the high-voltage continuous-current motor. There is doubtless a large field for any system which will secure some of the advantages of the single-phase system whilst retaining the good mechanical and electrical features of the continuous-current railway motor. I admit that I had in mind the high-potential continuous-current system in suggesting on page 258 the advisability of departing from present standard practice on suburban railways where excessively heavy trains have to be operated.

The speed torque characteristics of continuous-current and single-phase motors were discussed by Mr. Jenkin, and he has pointed out certain advantages in the characteristic of the latter. Whilst admitting these advantages for certain classes of service, I am of the opinion that they would be counterbalanced by disadvantages in other classes of service. The continuous-current motor characteristic could be varied to a considerable extent in the direction favoured by Mr. Jenkin by diminishing the saturation of the iron, but experience has determined its present usual shape as the proper mean between a constant-speed and a constant-power curve to suit suburban service. Mr.

Mr. Carter.

Jenkin's comparative figures for the Murnau line certainly show that in some cases the single-phase system proves the most suitable, which is quite in accordance with the opinion I hold.

Mr. McMahon operates a very interesting system, and is to be congratulated on the high distribution efficiency he obtains. Mr. McMahon's experience indicates that, for a line on which traffic is frequent and regular, the 3-wire system is well worthy of investigation.

Mr. Mordey's remarks are rather difficult to answer without traversing them in detail. He has deduced from Fig. 7 that the locomotive efficiency is low in suburban service. This is very true, for the locomotive efficiency depends largely on the class of service and only slightly on the efficiency of the motors. In discussing energy consumption I will agree with Mr. Mordey that motor efficiency is relatively unimportant, and an inexperienced driver is likely to be more detrimental in this respect than a motor of low efficiency. But in discussing the heating of the motors the efficiency is the only thing of importance. Lowering the efficiency by 10 per cent. increases the losses in the motor itself from perhaps 7 per cent. to 17 per cent. To dissipate these losses in motors of a given size requires that the number be more than doubled—that is, in service where 7 per cent. loss heats the motor to its limit. Hence the greater weight and other conclusions arrived at in the paper. The increased weight is a considerable objection in suburban service—as is clearly brought out in the course of the paper—but Mr. Mordey considers that I have removed my own objection by stating that for main line, high-speed long-distance work, weight is of secondary importance! With all deference to Mr. Mordey's great abilities, I cannot feel that I agree with his views.

The President.

The PRESIDENT: Gentlemen, we have had a very interesting paper and an exceedingly animated discussion, and I am sure the meeting will accord the author a very hearty vote of thanks for the contribution he has brought before us.

The resolution was carried with acclamation.

Proceedings of the Four Hundred and Thirty-fifth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 8, 1906—Mr. JOHN GAVEY, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on January 25, 1906, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

Charles Claremont Atchison. | Joseph P. McMahon.
John Lambert. | Henry Dewar Wight.
Lancelot William Wild.

From the class of Associates to that of Associate Members :—

John Ernest Addyman. | Cyril Renton Heron.

From the class of Students to that of Associate Members :—

James Robertson Barr. | Frank Herbert Fitt.
Arthur Clement Wilmot.

Messrs. V. A. Fynn and J. A. Aitkin were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Members.

Capt. the Hon. Alexander E. Bethell, R.N., C.M.G.
Hastings Fitz Edward Peet.
William Edward H. Scharina.

As Associate Members.

Walter Herbert Beilby.
George Percy Cole.
Louis John de Wynter.
Anton Falkenbach.
Arthur Jopling.
Henry G. Melly.
John Bulmer Morgan.
William Henry Fullarton Murdoch.
Cornelius George Nobbs.
Emile Rasecki-Morton.
Robert Llewellyn Willoughby Roberts.
Arthur Hugo Schultz.
George Stevenson.
Frederick Taylor.
Henry John Whitehead.

As Students.

John Archer.
Hugh Graham Barkley.
Alan Bartram.
Wynne Dallett Baxter.
Montague Butler Bean.
Arthur Keys Bentley.
Victor Broadbent.
Matthew Couchman.
William Craig.
Harold Craske.
Herbert Yates Denham.
Alexander James Duncan.
David Stevenson Ellis.
Richard J. England.
Norman Foot.
Arthur R. Fraser.
Albert Christian Freydendahl.
Robert H. Gardner.
Donald William Gollan.
Charles Bernard Gresham.
Hugh Melbourne Hart.
Walter Gear Harvey.
Bertram Hoyle.
Robert Gordon Jakeman.
William Munro Jennings.
John Jex-Long.
Harold William Johnson.
James C. Kelso.
Hasan Camrudin Amirudin A. Latif.
Stanley Leigh.
Hugh Vaughan Lewis.
Alexander Macfarlane.
John Thornley Maden.
Thomas H. Melville.
John William Whittier Munro.
Allen Nuttall.
Samuel Ogden.
C. D. Jeffery Orchard.
Arthur Howard Page.
John Henry Palmer.
Hubert Francis Parish.
Henry Cyril Price.
William Traill Ritchie.
Edward Claydon Rix.
John Ambrose Sadd.
James Austin Smith.
Percy H. H. Squier.
Edward John Stevens.
William Charles Stewart.
William Whitelegge Thomas.
Herbert George Tisdall.
Edgar Watkinson.
Oswald Welch.
Gilbert Whitaker.
Franz Workman.
Louis Theodore Young.

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. A. von Boschan, G. B. Byng, M. B. Byng, A. D. Constable, The Electrician Printing and Publishing Co., J. T. Haynes, D. Henriques, H. Hirst, T. E. Ingoldby, E. Mascart, J. M. Smyth; and to the *Benevolent Fund* from Messrs. G. B. Byng, M. B. Byng, J. T. Haynes, K. Hedges, H. Hirst, S. Insull, H. A. Irvine, W. E. Russell, to whom the thanks of the meeting were duly accorded.

The discussion on Mr. F. W. Carter's paper was concluded (see page 268); and the meeting adjourned at 9.30 p.m.

Proceedings of the Four Hundred and Thirty-Sixth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 22, 1906—Mr. W. M. MORDEY, Vice-President, in the chair.

The minutes of the Ordinary General Meeting held on February 8, 1906, were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

W. J. Crampton. | T. H. Schoepf.

From the class of Associates to that of Members : —

C. H. Ellison.

From the class of Associates to that of Associate Members :—

J. Eustace. | W. Noble.

From the class of Students to that of Associate Members :—

C. Cuthbertson.

Messrs. W. W. Cook and J. H. Johnson were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Members.

Edward C. De Segundo. | Johannes Sigfrid Edström.

As Associate Members.

John Frederick Avila.
William Edward Claret.
Thomas Ingram Craig.
William Dobson.
Arthur Penrhyn Drake.
Sidney Lynch.
Walter Stanley Mackrill.
John Edgar Mallalieu.

As Associate.

Harry Benedetto Renwick.

As Students.

Charles Edmund Abell.
Leonard Stephen Admans.
Alfred George Barnard.
James Elphinstone Baty.
Frank Blair.
Joseph Bernard Cahill.
Michael Richard Cahill.
Harold John Turner Case.
Lee Purejoy Causton.
Rene Armand Coffin.
Raymond Correa.
Ralph Crosbie-Hill.
Henry James Goddard Davison.
Frederick Cecil Faraker.
The Hon. Edward Fulke French.
Erik Friis-Smith.
John Robertson Geddes.
Gerald Albert Gilmer.
Charles Norman Good.
Reginald Gorham.
John Greenhalgh.
Thomas Edgar Harley.
Richard Harris.
Lewis Henshaw.
Hoon Yu Hsu.
Harold Vernon Hutt.
Joseph Lawson.
Charles George Le Feuvre.
Gustave Michael Lembcke.
Lionel Douglas Leonard.
Harold Marsden.
William Charles Massie.
Henry Rogers Massingham.
Ernest Müller.
Arthur Wellesly Odlum.
Edward Stanton Ritter.
John Frank Rose-Innes.
Francis Powell Talboys.
George H. Taylor.
James Ardern Taylor.
Hugh Gordon Walker.
Wai Tsen Wang.
Thomas Henry West.
William Westbrook.
Sidney Percy Whelan.
James Whitehouse.
Alexander Forrest Wylie.
John Henry Samuel Yates.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. H. Alabaster, Gatehouse & Co., M. Ascoli, E. Bennis & Co., Ltd., St. J. Clarke, the Commissioners of the St. Louis Exhibition, A. Constable & Co., Gauthier Villars, A. Gay, L. Gerard, The Radcliffe Library, Oxford, W. N. Twelvetrees, The U.S.A. Bureau of Standards, C. H. Yeaman; to the *Building Fund* from Messrs. R. H. Burnham, M. M. Gillespie, H. W. Kolle, W. McGeoch, F. P. Seager, J. F. C. Snell; and to the *Benevolent Fund* from Mr. J. R. P. Lunn, to whom the thanks of the meeting were duly accorded.

The following paper was read and discussed :—

CRANE MOTORS AND CONTROLLERS.

By CLAUDE W. HILL, Member.

(*Paper read February* 22, 1906.)

There is at present considerable diversity of practice in determining the size and rating of motors for crane work, the object in all cases being to obtain a size of motor such that in the ordinary working of the crane its temperature rise shall not exceed what is usually considered to be a safe figure, this in English practice being generally 75° F. If the temperature rise is less than this the motor is larger and more expensive than is necessary, while if the rise is higher there is the possibility of injury to the motor.

In the case of cranes for a specified duty going through a known cycle of operations all day long the work of the motor is known beforehand, and the most convenient method of specifying and testing is to specify that the motor, when run continuously at a given H.P., shall in a stated time attain a temperature rise which shall correspond with that which it will attain when driving the crane all day long in the usual way.

The point to be determined here is the method of calculation by which we can ascertain the load and time which shall produce a rise of temperature equal to that produced in the usual way of working. This is one of the points with which it is proposed to deal in this paper.

It is sometimes desired by purchasers that the motor shall be tested by running it intermittently at its stated H.P. for a sufficient time for its temperature to become steady. This is an unnecessarily expensive way of testing, and is moreover useless, because we cannot introduce the same starting conditions as to friction of repose and inertia load as will be encountered in actual work.

In the general run of crane work we do not know beforehand what the average work of the crane will be, so that the size of the motor has to be a more or less fortunate guess. It is owing to this uncertainty that the diversity of practice already mentioned has grown up.

Some of the more common methods of specifying are as follows:—

(1) The H.P. required to lift or move the load, plus gearing losses, is taken as the B.H.P. of the motor. The motor is specified to be of this power, with a load factor of 20%, 25%, etc. (as the case may be), with continuous runs not exceeding, say, five minutes and temperature rise of 75° F. Thus a motor of 10 B.H.P. with 20 per cent. load factor, if worked intermittently at 10 B.H.P. with periods of rest four times as long as the periods of working, the latter in no case exceeding five

minutes, would have a final mean temperature 75° F. above the atmosphere.

(2) The H.P. required to lift or move the load, exclusive of gearing losses, is taken as the B.H.P. of the motor. The motor is specified to be of this power and to be capable of exerting double power for a few minutes.

(3) The H.P. required to lift or move the load, plus gearing losses, is taken as the B.H.P. of the motor. It is specified to maintain this power on a continuous run of one hour with a rise of 75° F., and to maintain half this power for four hours with the same rise of temperature.

(4) The H.P. required to lift or move the load, plus gearing losses, is taken as the B.H.P. of the motor. It is specified to maintain this power on a continuous run of ¼, ½, or 1 hour, as the case may be, with a rise of temperature of 75° F.

In cases where the work of the crane cannot be exactly ascertained beforehand, the author considers that the last method of specifying and testing is most convenient both to the purchaser and the maker.

The decision as to whether a ¼, ½, or 1 hour motor is most suitable in such cases cannot be settled by calculation, but is a matter for judgment based on previous experience. An examination into the characteristics of ¼, ½, and 1 hour motors is, however, of assistance in forming a decision, and is another point with which it is proposed to deal in the present paper.

Rise of Temperature.—For the calculations relating to the rise of temperature the author has availed himself of Goldschmidt's paper,* and has used the formula given by Professor Silvanus Thompson in the discussion—

$$C_t = M \times \left(1 - e^{-\frac{t}{T}}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which M is the final rise of temperature of the motor when running continuously, C_t the rise of temperature at any time t from commencement of run, and T the time in which the rise of temperature M would be attained if there were no loss of heat. Time being taken in minutes.

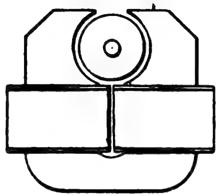
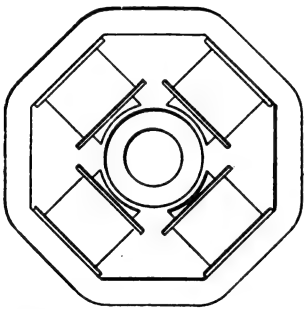
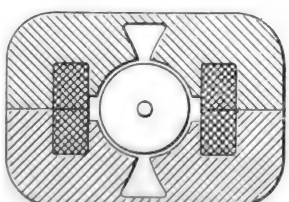
The value of M is found by formula No. 2, which was first given by Mr. W. B. Esson † in his paper at this Institution in 1888—

$$M = \frac{C\,W}{S} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

in which C represents the rise of temperature for an energy loss of one watt per square inch of radiating surface, W the watts, and S the surface in square inches.

For purposes of comparison some values of C taken from machines of widely different design are given in Fig. 1. In Fig. 2 two curves are given, taken from the first machine in Fig. 1, showing how the value of C, both for the armature and magnets, varies with the speed.‡

* *Journal Institution of Electrical Engineers*, vol. 34, p. 660.
† *Ibid.*, vol. 19, p. 148.
‡ Similar curves are given in Parshall and Hobart's "Electric Generators," and Professor Thompson's "Dynamo-Machinery."

No.	Type of Machine.		Peripheral Speed of Armature, Feet per Min.	Armature C.	Magnet.	
					C taking outer surface.	C taking whole surface.
1		Bipolar Open Type Drum with Armature overhead	2,914	20·5	50·25	119
2		Same Machine	1,850	27·4	59·36	140
3		Same Machine	925	47·0	69·8	164
4		Four-pole Open Type Drum Armature, having end connections which were very open and set up a strong draught	1,734	12	27	—
5		Totally enclosed Bipolar Drum with Toothed Armature	1,507	62·5	—	142

The temperatures were in all cases taken by thermometer, and on six-hour runs.

In the case of a machine running intermittently, in order to determine its ultimate mean temperature we require to know the rate at which its temperature rises when working and the rate at which it cools when stopped. By taking the differences of rise and fall over the successive periods of work and rest and summing them, we obtain a curve which ultimately becomes flat.

The Heating Curve.—In order to determine the value of T in formula No. 1 we require to know the specific heat and volume of that portion of the machine to which the formula is being applied. For an insulated coil we require to know the mean specific heat, which we can derive from the respective specific heats of copper and cotton insulation.

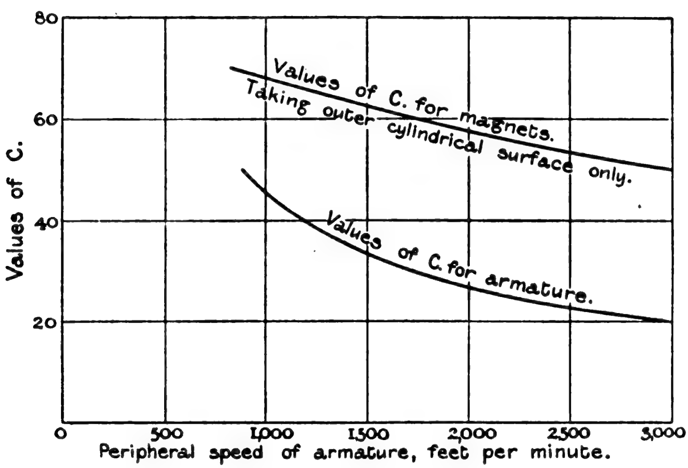


FIG. 2.

The specific heat of such a coil will vary with the space factor, and, taking copper at 0·095 and cotton insulation at 0·38, the curve, Fig. 3, has been prepared showing the relation. A further curve, Fig. 4, has been prepared from this, showing the relation between the space factor and the watts per cubic inch which would raise the temperature of the coil at the rate of 1° C. per second if there were no losses.

From the known dimensions of the coil the value of T can be found from formula No. 3—

$$T = \frac{M W}{60 w_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

in which w_1 are the watts per cubic inch of coil and W the watts per cubic inch (taken from Fig. 4) which would cause the temperature of the coil to rise at the rate of 1° C. per second. In the case of open machines a curve based upon the above value of T seems to agree very well with the curve found by experiment, as may be seen in Mr.

Goldschmidt's paper and the curve in Fig. 5. With enclosed motors, in determining T it appears to be necessary to include something more

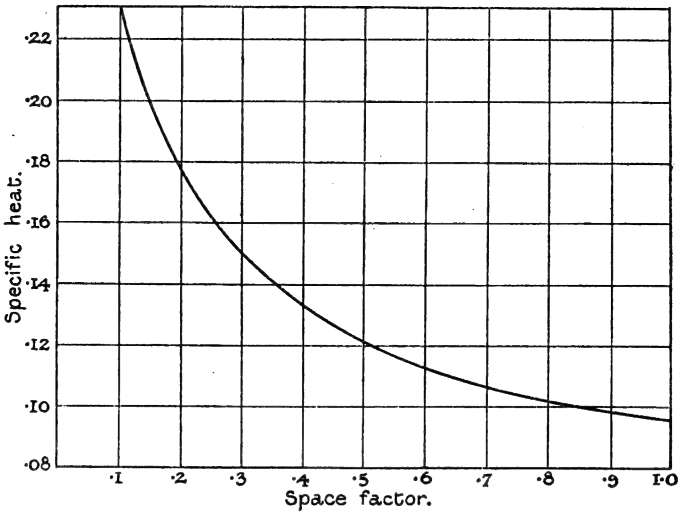


FIG. 3.

than the dimensions of the coil, as some portion of the machine carcase in proximity to the coil is heated to practically the same temperature.

Thus, if we base T on the dimensions of the coil only, we get a

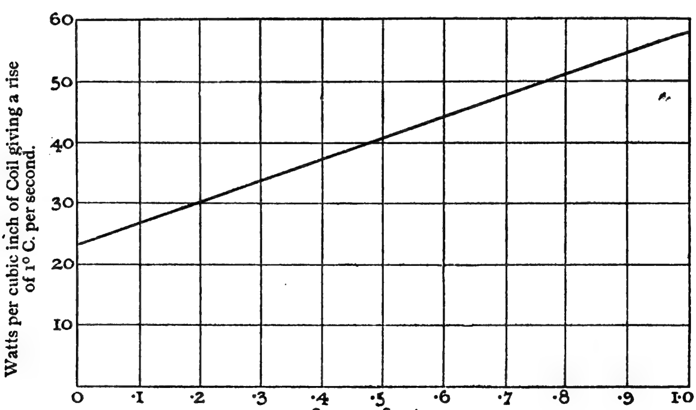


FIG. 4.

curve which is considerably to the left of the observed one; while if we base T upon the specific heat and volume of the entire machine, we get a curve which slopes away very much to the right of that found

by experiment. Thus, in finding the watts per cubic inch, upon which the value of T depends, we must add to the volume of the coil some portion of the volume of the machine carcase; but as the amount of this additional volume is indeterminate, we may instead multiply T (taken from the known dimensions of the coil) by a constant K found by experiment from the nearest parallel case.

The value of K is given by the formula No. 4—

$$K = \frac{t \log e}{T \log\left(\frac{M}{M - C_t}\right)} \quad \ldots\ldots\ldots \quad (4)$$

in which t is the time from the commencement of the run at which a temperature is taken, C_t the temperature at that time, and M, as before,

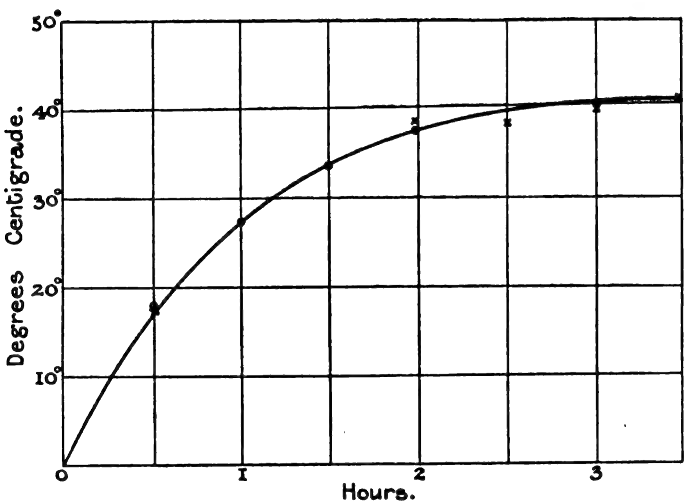


FIG. 5.

Space Factor, 0·38. Watts per cubic inch, 0·457. Watts per 1° C. per second, 36·75. M = 43. T = 58. Observed points, ×. Calculated points, ⊙.

the final temperature to which the coil rises. Examples are given in Figs. 6 and 7, taken from the totally enclosed machine shown in Fig. 1. This machine was of somewhat special design for a special purpose, and possibly the discrepancies between the various curves would not be so great with a machine of more ordinary type. Also it should be mentioned that the armature test was made with a current 2·25 times the normal, and that it was not run up to the final temperature of 135° C., this being calculated from the constant 62·5 found from a six hours' run at normal load, in which unfortunately no intermediate readings were taken.

The Cooling Curve.—An example of a cooling curve, taken off a coil of dimensions similar to that of which the heating curve is given in Fig. 5, is shown in Fig. 8. This curve may be calculated by reversing

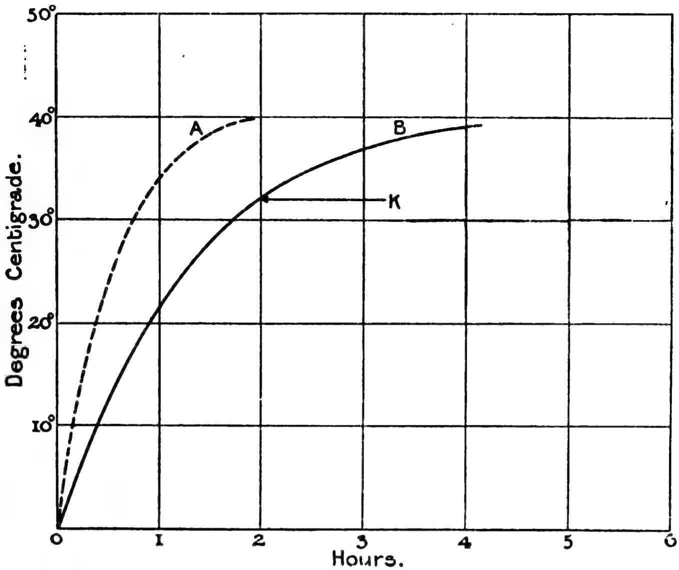


FIG. 6.

Curve A (Calculated).

Space Factor, 0·28.
Watts per cubic inch, 0·675.
Watts per 1° C. per second, 33.
M = 41. T = 33·5.

Curve B (Observed).

T = 33·5 × 2·36 = 79·1.

$$K = \frac{120 \times \cdot 4343}{33 \cdot 5 \times \log\left(\frac{41}{41 - 32}\right)} = 2 \cdot 36.$$

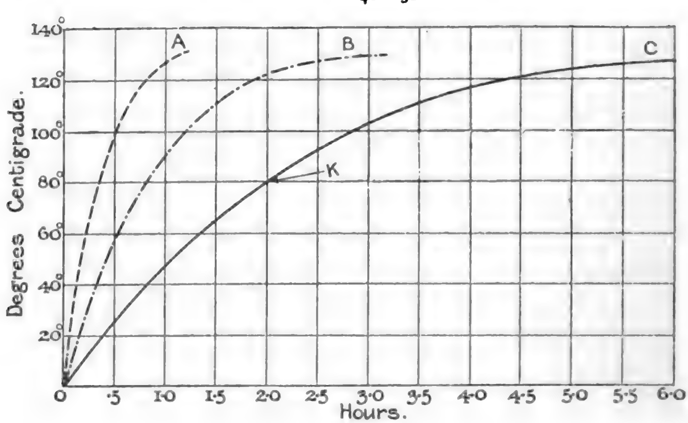


FIG. 7.

Curve A (Calculated for Armature Coils only).

Space Factor, 0·34.
Watts per cubic inch, 3·66.
Watts per 1° C. per second, 35·2.
M = 135. T = 21·6.

Curve B (Calculated for whole Armature).

Specific Heat of whole Armature, 0·117.
Watts per 1° C. per second, 40·5.
Watts per cub. in. (iron and copper losses) 1·78,
M = 135. T = 51·5.

Curve C (Observed).

T = 51·5 × 2·62 = 135.

$$K = \frac{120 \times \cdot 4343}{51 \cdot 5 \log\left(\frac{135}{135 - 79 \cdot 5}\right)} = 2 \cdot 62.$$

Formula No. 1, but multiplying T by a constant K′, which must be found by experiment, as it will be found that, although all machines cool down at a slower rate than they heat up, the rate of cooling varies with the design of machine.

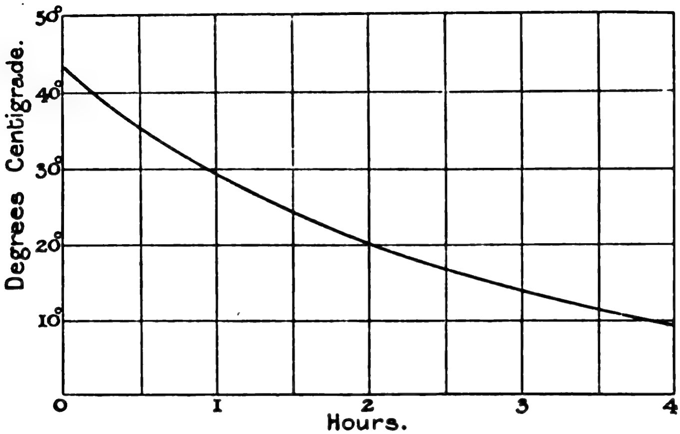


FIG. 8.

Machines of ¼, ½, and 1 Hour Ratings.—In Table I. the temperature data have been worked out for three sizes of machine—A, B, and C.

For each machine a series of temperature curves such as those shown in Fig. 9 have been calculated, and from these, curves such as Fig. 10 have been prepared showing the relation between length

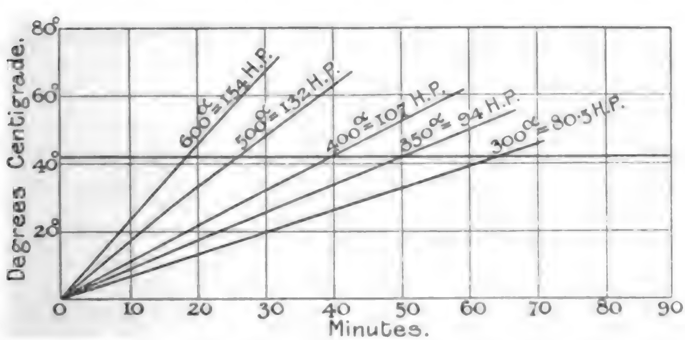


FIG. 9.

of run and H.P. for a temperature rise of $41{\cdot}5^\circ$ C. (75° F.). For each machine the load has been worked out for a temperature rise of $41{\cdot}5^\circ$ C. on a run of ¼, ½, and 1 hour, the winding being the same for each rating.

It will be noted that notwithstanding the heavy loads the reactance

voltages, even at the ¼-hour ratings, are not excessive. If, however, the machines were wound for a circuit of double the voltage (*i.e.*, 440 instead of 220), these reactance voltages would also be doubled, and it would then be desirable to use commutating poles.

The armature data have been worked out for each machine, but magnet data have only been got out for machine C. These figures show that as T has not the same value for both armature and magnet, their respective rises of temperature, if the windings remain the same, will not be the same at the different ratings.

Thus in the example given the armature and magnet rises practically correspond for the ½-hour rating, while for the ¼-hour the magnet rise is greater, and for the 1 hour less, than the armature.

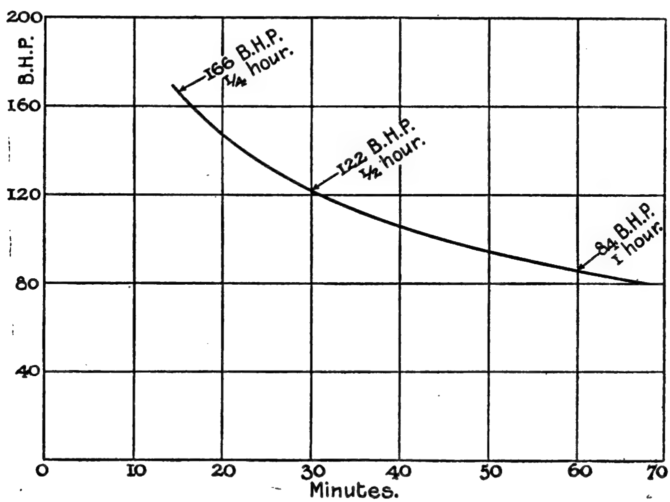


FIG. 10.

It has been generally noted among crane-makers that ¼-hour rated motors have a habit of burning out with a facility which has been somewhat surprising to them.

If, however, we look into the matter we find that it is not so surprising that this class of machine should fail with quite moderate overloads.

A sudden evolution of heat such as would be caused by an overload does not immediately spread throughout the armature. Being localised, it heats a smaller volume, so increasing the rate of rise, while at the same time the amount of heat generated is proportional to the square of the current.

On the above assumption some figures of a rough character have been worked out, and are given in the lower part of Table I. These show how very rapidly the rate of increase of temperature increases with the overload on short-rated machines.

From the figures in Table I. we may conclude that the ¼-hour motor has a very limited field of application, while the ½-hour motor is suitable for the generality of cranes having low load factors, and the 1-hour motor is suitable for cranes which are worked moderately hard.

Motors Working on a Known Cycle.—Taking the simplest case of a motor working at a given H.P. for a stated time and then standing for a stated time, the final mean temperature, above the atmosphere, will be attained when the rate of heating × the time of working equals the rate of cooling × the time of standing. This has been worked out for the machines A and C, and in Figs. 11 and 12 curves are given showing

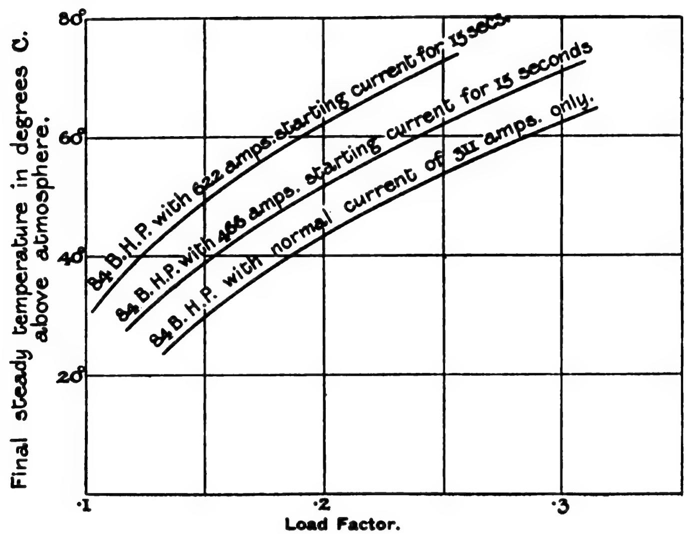


FIG. 11.

Working period one minute in each case.

MACHINE C.—84 B.H.P., 440 r.p.m., 220 volts, 311 amperes.
Rise of Temperature in continuous run of 1 hour at 84 B.H.P. = 41·5° C.

$$\text{Load Factor} = \frac{\text{Time of working}}{\text{Time of working} + \text{Time of stopping}}.$$

the relation between load factor and final temperature when the machines are run at the same H.P. as would result in a rise of temperature of 41·5 C. in one hour's continuous run.

We note that for the same rise of temperature the load factor of the small machine is greater than that of the large one.

This illustrates the point that for a given load factor and rise of temperature the larger the machine the longer must its time rating be.

A point which has to be taken into consideration is that each time the motor is started its current, for a time, exceeds the normal to a greater or less extent, and we ought, therefore, in our calculations, to take the mean current during the working period, and not merely the

current after the motor has settled to its steady speed. If the working period is short, we may for practical purposes take the equivalent current during the period to be as given in formula No. 5—

$$\sqrt{\frac{C_s^2 t_1 + C_n^2 t_2}{t_1 + t_2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

in which C_s is the mean starting current, t_1 the starting period, C_n the normal running current, and t_2 the normal running period. In Fig. 11 for machine C three curves are given, one in which no account is taken of the starting current, a second in which the mean starting current is taken at 1·5 times the normal, and a third in which it is taken at twice the normal.

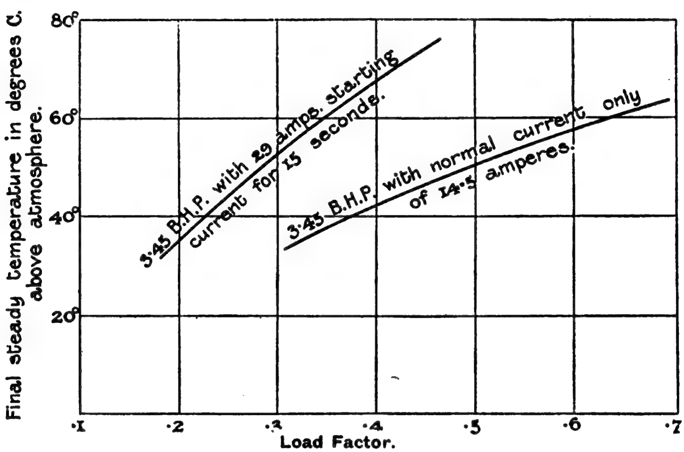


FIG. 12.

Working period one minute in each case.

MACHINE A.—3·45 B.H.P., 490 r.p.m., 220 volts, 14·5 amperes.
Rise of Temperature in continuous run of 1 hour at 3·45 B.H.P. = 41·5° C.

$$\text{Load Factor} = \frac{\text{Time of working}}{\text{Time of working} + \text{Time of stopping}}$$

In Fig. 12, for machine A a curve is given for normal current only, and a second in which the mean starting current is twice the normal. In all these cases the starting current is taken as being on for fifteen seconds out of a working period of one minute.

An examination of these curves shows how very necessary it is to take into account the starting currents when the working periods are short.

The Load Factor.—In the general run of crane work the load factor is low, as might be expected from the fact that ½-hour motors have been found satisfactory. The lowness of the load factor is due not only to the motors having fairly long standing periods, but also because they do not exert their full power every time.

Where the motor exerts its full power each time, the load factor is given by the formula No. 6—

$$f = \frac{t'}{t' + t''} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

in which t' is the time of working, and t'' the time during which the motor is stopped.

Where the power varies we have to include the H.P., and the formula then becomes—

$$f = \frac{H\,P_1 \times t'}{H\,P \times (t' + t'')} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

in which $H\,P_1$ is the H.P. exerted during the time t' and $H\,P$ is the rated H.P. of the motor.

The load factor so found is correct so far as the supply of current to the motor is concerned, but is not correct with respect to the heating of the motor, which is proportional to the internal losses, which, again, are approximately proportional to the square of the H.P.

For the purpose of dealing with the motor temperature we require, then, a second load factor given by formula No. 8—

$$f_1 = \frac{H\,P_1^2 \times t'}{H\,P^2 \times (t' + t'')} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

We may call the first the external load factor and the second the internal.

In Tables II., III., and IV. are given some test figures taken from an overhead travelling crane which was designed by the author and constructed by the Cleveland Bridge Co.

From these figures the external and internal load factors have been calculated and added at the foot of each table.

On the hoisting gear a shunt motor is used, giving a regenerative effect when lowering, and so reducing the external load factor. On the other hand, the internal load factor is slightly increased by the regenerative current, as the heating of the machine depends only on the passage of a current through it, and not upon its direction. This method of using a shunt motor to drive the hoisting motion of cranes has been in use by the Cleveland Bridge Co. for nearly 2½ years on several cranes, the advantages being complete control over the speed of lowering, a slight economy in current consumption, and a considerable economy in wear and tear of brake gear.

In settling the test to be specified for a crane motor, the internal load factor is an important figure.

Having (either by the test figures of a previous crane or by calculation) constructed a table such as Table II., and found the load factor, and having also determined the H.P. necessary for the crane when fully loaded, we may by means of curves such as those of Figs. 11 and 12 ascertain the length of run at the full H.P. of the motor which will give the same rise of temperature as will be attained when the motor is driving the crane in regular work.

Figs. 13 to 16 are examples of amperemeter diagrams taken from the overhead crane of which figures are given in Tables II., III., and IV. Figs. 17 and 18 are from a 5-ton derrick crane, and Fig. 19 from a 15-ton Goliath. In the two latter cases the electrical driving arrangements only were designed by the author, and not the cranes. These diagrams show the relative starting and running currents, from which the equivalent mean currents during each run have been calculated. They also show the regenerative currents obtained when lowering loads with the shunt motors.

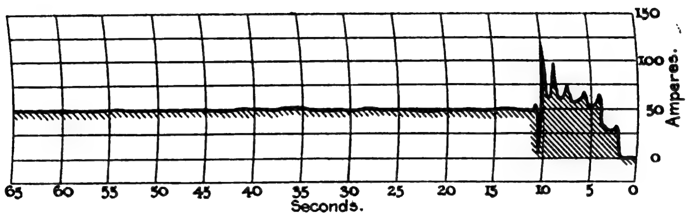


FIG. 13.

Lifting 15 *Tons.*

Mean starting current, 53 amperes.
„ running „ 50 „
„ during run 50·4 „

Controllers.—In the design of a controller there are two principal objects to be attained. Firstly, the height of the current peaks must be limited to such an amount as may be convenient, having regard to the circuit-breakers and fuses; and secondly, the motor to which the controller is connected must be brought to full speed within such time as may be required. In order to attain full speed in the shortest possible time the height of current peak on each step of the con-

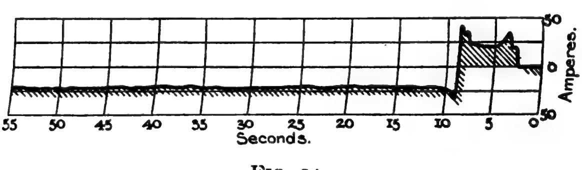


FIG. 14.

Lowering 15 *Tons.*

Mean starting current, 25 amperes.
„ running „ 21 „
„ during run 21·5 „

troller should be the maximum permissible. When the controller is on the first step the current simply depends upon the voltage of the circuit and the resistance of the motor and controller. At this point, then, the resistance in the controller must be such that at the moment the circuit is made the current which flows shall not exceed the maximum allowable. This decides the total amount of resistance, and in order that the current shall rise to the same value, each time the

controller is moved a step forward the resistance must be graded in accordance with formula No. 9—

$$Ra, b, c, \&c. = r \times \left(\frac{C_1}{C_2}\right)^{n-1} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (9)$$

in which R*a* is the total resistance with the controller on the first step, R*b* the resistance on the second step and so on, *r* the resistance of the motor, C_1 the maximum current, and C_2 the value to which the current falls before moving on to the next step and *n* the number of steps in circuit at any time.

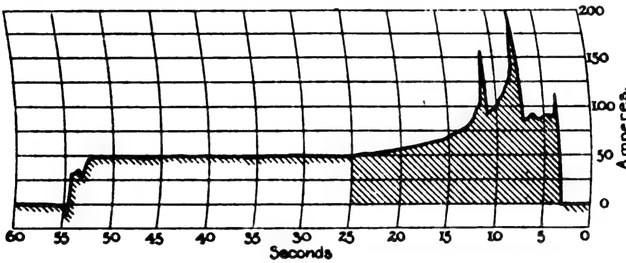


FIG. 15.

Travelling 30 *Tons.*

Mean starting current, 79 amperes.
" running " 50 "
" during run 67·5 "

From the above formula we can also determine the number of steps which a controller must have in order to fulfil the given requirements, by means of formula No. 10—

$$n = 1 + \frac{\log R - \log r}{\log \left(\frac{C_1}{C_2}\right)} \quad . \; . \; . \; . \; . \; . \; . \quad (10)$$

As an example of the application of the above formula we may compare Fig. 13 with Fig. 19. The motors and controllers in both cases were identical, but the controller of Fig. 19 had the resistances graded in accordance with the formula, while that of Fig. 13 had not. It will be noted that in Fig. 13 the mean starting current is 53 amperes with a maximum of 140, a ratio of 2·6 to 1, while in Fig. 19 the mean starting current is 58·6 amperes with a maximum of 80, the ratio being in this case 1·36 to 1, so enabling the circuit-breaker to be set much closer to the running current of the motor.

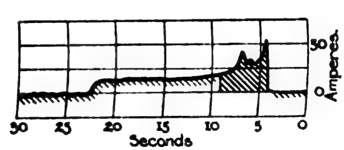


FIG. 16.

Traversing 30 *Tons.*

Mean starting current, 28 amperes.
" running " 14 "
" during run 19 "

In addition to the two principal requirements above mentioned, the

controller is sometimes required to be capable of bringing the motor down to a very slow speed. For this purpose additional steps have to be provided, with further resistance in addition to that found by the above formula.

As an example of the application of the formula a controller design has been worked out for machine C ½-hour rating, and the complete starting diagram is given in Fig. 20. In this it is assumed that the slowest speed required will be 10 per cent. of full speed, and that the

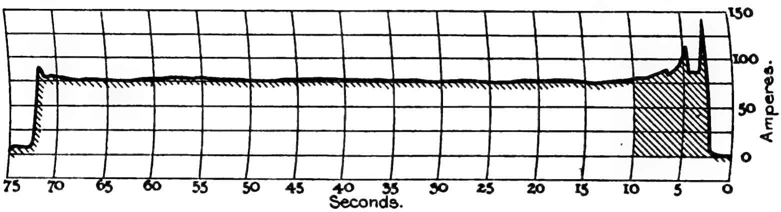


FIG. 17.

Lifting 5 *Tons.*
Mean starting current, 86·5 amperes.
„ running „ 79 „
„ during run 83·7 „

lightest load will be equivalent to ⅓ the full torque of the motor, and it is further assumed that a mean starting current 25 per cent. in excess of the normal running current is required to give the necessary acceleration.

The full lines in Fig. 20 show the diagram when starting on full load, and the dotted lines the diagram when starting on the lightest load.

The first three steps are slow-speed steps, and the remaining five are

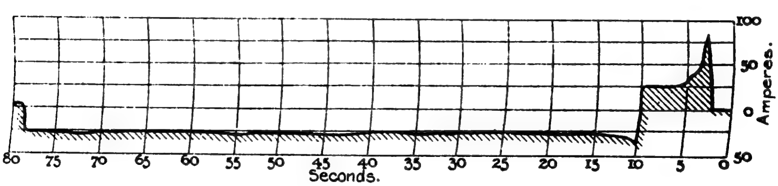


FIG. 18.

Lowering 5 *Tons.*
Mean starting current, 31·9 amperes.
„ running „ 25 „
„ during run 25·8 „

acceleration steps. The motor can, however, be run with the controller on any step without the height of the current peaks exceeding those shown.

Although this controller will reduce the speed to 10 per cent. of full speed on full load and on the lightest load, it will not do so on intermediate loads, as will be seen from Fig. 21. To do so using series resistance only would require an altogether impracticable number of steps.

A generally lower speed with any load from the lightest to full load without increasing the number of steps may be obtained by arranging resistances in parallel with the armature, in addition to those in series on the slow-speed steps.

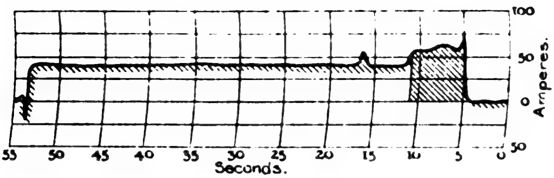


FIG. 19.

Lifting 10 Tons.

Mean starting current, 58·6 amperes.
" running " 42·5 "
" during run 43·7 "

By using a resistance of 0·1 ohm in parallel with the armature on the first step, 0·075 ohm on the second step, and 0·065 ohm on the third step, we obtain the speeds, torques, and currents shown on Fig. 22, which it will be seen give slow speeds over a wide range of load. This diagram shows the currents on the first three steps, while the

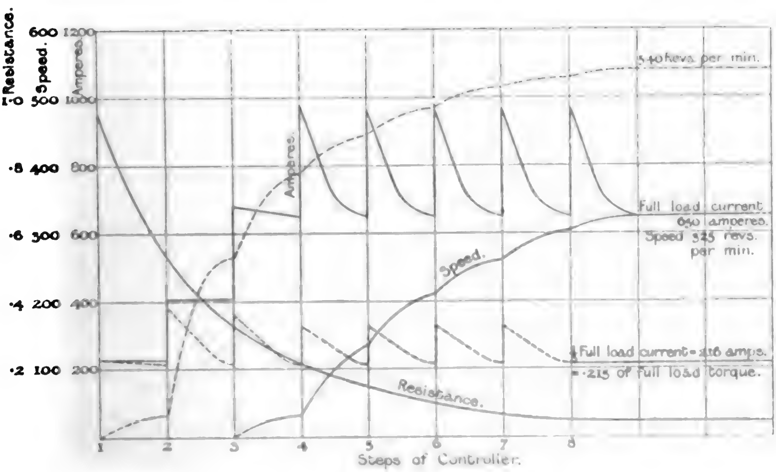


FIG. 20.

Full lines indicate controller diagram with full load.
Dotted " " " " " load requiring ⅓ full current = approx. ⅕ full torque.

currents on the remaining steps are as shown in Fig. 20. One advantage of using parallel resistances for the slow-speed steps is that the current through the armature when standing exceeds the running current by a greater amount than when series resistances are used, so that the machine can exert a greater starting torque on these steps.

The controller described is only suited for a series motor and positive driving, so that it is necessary to provide in the hoisting train

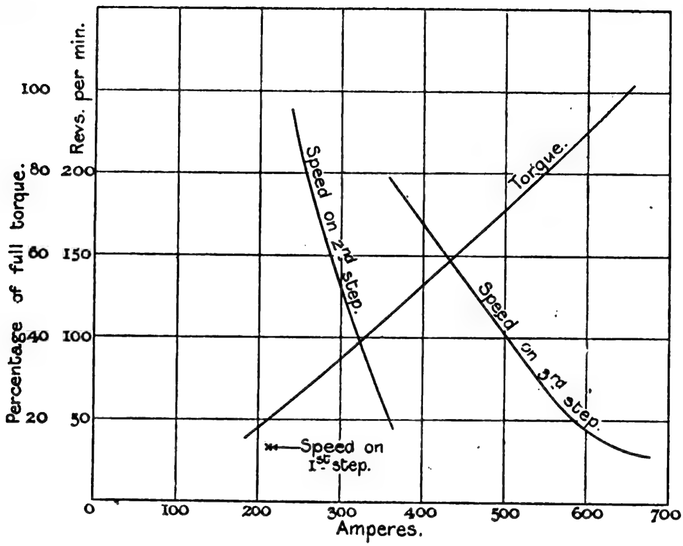


FIG. 21.

an automatic mechanical brake which will prevent the load overhauling the motor.

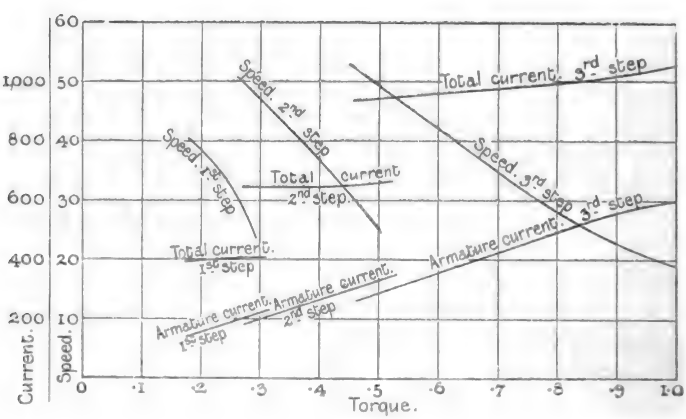


FIG. 22.

When it can conveniently be arranged, it is better to use a shunt motor and regenerative control for lowering as already described.

APPENDIX.

The following formulæ, most of which are based on the curves, etc., in the foregoing paper, are useful for the purpose of determining times and temperatures and the relation between the temperature attained when working intermittently with different load factors and that attained when working continuously.

Value of T.—When designing a machine in detail, formula No. 3 may conveniently be used. It will, however, be noted that as M and w_1 both vary in proportion to the watts lost in the coil, the value of T depends only on the space factor and dimensions of the coil, and is independent of the current passing through it.

The value may then be found by the formula—

$$T = \frac{W\,C\,V}{60\,S} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

in which V is the volume in cubic inches and S the surface in square inches, W being taken as before from curve No. 4. The formula of this curve being—

$$W = 23{\cdot}12 + 34{\cdot}88\,g \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

in which g is the space factor, the formula for T becomes—

$$T = \frac{(23{\cdot}12 + 34{\cdot}58\,g)\,C\,V}{60\,S} \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Relation of Intermittent to Continuous Running.—The formula for the heating curve being—

$$C_t = M \times \left(1 - \epsilon^{-\frac{t}{T}}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

for the cooling curve—

$$C_t = M \times \epsilon^{-\frac{t}{TK'}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1a)$$

and for the ultimate rise of temperature when running continuously—

$$M = \frac{C\,W}{S} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

we may by means of these formulæ calculate such curves as Fig. 11, in which is shown the relation between load factor and ultimate temperature rise of a machine working intermittently which, if worked continuously at the same load, would have a temperature rise of 41·5° C. in one hour.

The curve may alternatively be arranged as shown in Fig. 23. This has been worked out for machine A, for a case in which the mean starting current is twice the running current as shown on the small diagrams Fig. 24 A, B, etc., and shows the relation between load factor and H.P. which will give an ultimate temperature rise of 41·5° C., and also the length of continuous run which for each H.P. will produce

the same rise of temperature. Thus, turning to the curve, for a load factor of 0·25, the machine may be worked at 3·4 H.P. for an ultimate rise of 41·5° C., and the temperature rise will be the same if the machine is worked continuously for one hour at this H.P.

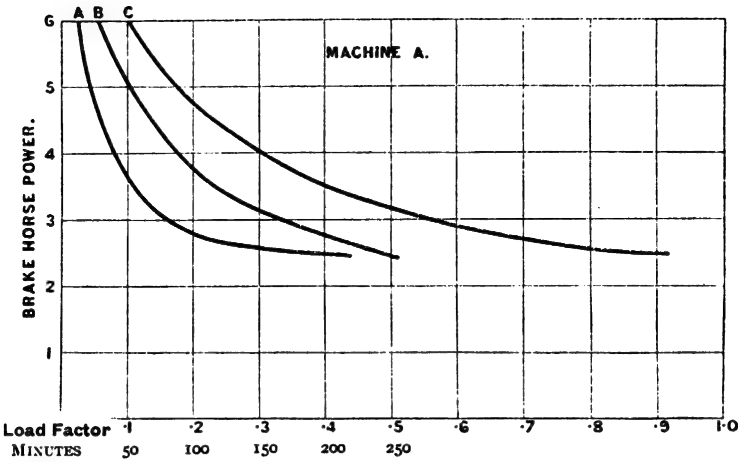


FIG. 23.

A. Time of continuous run at rated H.P. for a rise of 41·5° C.
B. Load Factor for a rise of 41·5° C. when starting current = normal current × 2 for 15 seconds out of 60.
C. Load Factor for a rise of 41·5° C. when starting current does not exceed normal running current.

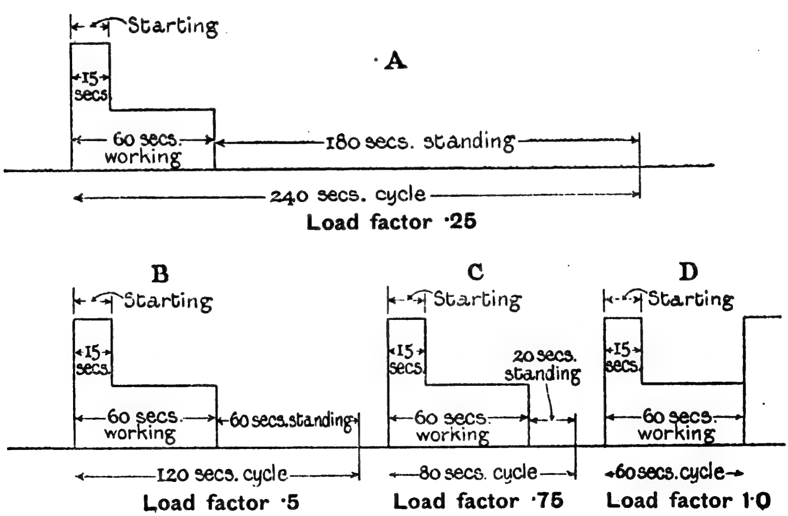


FIG. 24.

In addition to the formulæ already given, we require, in calculating curves such as Figs. 11, 12, and 23, to be able to determine the load factor and ultimate temperature rise when working intermittently.

As has already been remarked in the paper, the temperature of the machine when working intermittently on a definite cycle, that is, with a definite load factor (see Formula No. 6), will be steady when the mean rates of heating and cooling are inversely proportional to the times of working and standing. The load factor (or cycle) with which a machine may be worked in order that its mean temperature shall not exceed that attained when working continuously at the same H.P. for a given time, may be obtained graphically from the heating and cooling curves, but it can be found more expeditiously by calculation if we assume that the mean rates of heating and cooling correspond to the rates of heating and cooling at the mean temperature required. This assumption is not, of course, quite correct, but the error which it introduces is so minute as to be negligible in the case of machines, such as crane motors, which work for exceedingly short periods. We may then calculate the load factor from the differential coefficients of the curves, without taking into account the times of working and standing.

The differential coefficient of the heating curve (Formula No. 1) is

$$\frac{d\,C_t}{dt} = \frac{M}{T} e^{-\frac{t}{T}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

which can be expressed more simply as

$$\frac{d\,C_t}{dt}\,(\text{heating}) = \frac{M - C_t}{T} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14a)$$

This gives the rate of heating when the machine has attained the required temperature rise C_t on a continuous run of the given time t. The rate of cooling at this temperature is

$$\frac{d\,C_t}{dt}\,(\text{cooling}) = \frac{C_t}{T\,K'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14b)$$

The formula for the load factor is then

$$f = \frac{\dfrac{C_t}{T\,K'}}{\dfrac{M - C_t}{T} + \dfrac{C_t}{T\,K'}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

The calculation is simplified by the fact that while the rate of heating at the given temperature increases with the load, the rate of cooling at this temperature remains constant.

TABLE I.

VOLTS IN ALL CASES 220.

Machine	A.			B			C.		
Rating	¼ Hour	½ Hour	1 Hour	¼ Hour	½ Hour	1 Hour	¼ Hour	½ Hour	1 Hour
Brake Horse-Power	5·62	4·4	3·45	53	38·5	27	166	122	84
Revolutions per Minute	345	420	490	360	395	450	320	360	440
Efficiency	69·5	76·5	80·5	83	87·5	90	86·25	89·25	91
Armature:									
Temperature Rise at Rated Load	41·5	41·5	41·5	41·5	41·5	41·5	41·5	41·5	41·5
M.	240	130	82	425	235	128	575	295	150
T.	80	80	80	150	150	150	188	188	188
Watts per Cubic Inch	3·5	1·9	1·18	3·75	2·05	1·1	4·1	2·1	1·05
Watts per Square Inch	3·8	2·08	1·3	7	3·65	2·1	9·2	4·6	2·4
Current Density	5,500	3,900	2,900	6,300	4,450	3,000	4,950	3,300	2,320
Reactance Voltage	2·8	2·4	2·1	3·5	2·6	2	4·9	4	3·3
Approximate Temperature rises with Overloads: Temperature Rise per Minute at Rated Load	2·76	1·38	0·69	2·76	1·38	0·69	2·76	1·38	0·69
Ditto, Current by 2	14·3	6·3	3·2	11·5	2·8	1·9	15	6·4	2·5
" " 3	45·8	17	8·2	42·5	12	4·6	50	18·2	6·6
" " 4	147	39	17	175	28·8	9·6	172	42	13·4
Magnet:									
Temperature Rise at Rated Load	—	—	—	—	—	—	45°	42°	35°
M.	—	—	—	—	—	—	320	162	73·5
T.	—	—	—	—	—	—	99	99	99
Watts per Cubic Inch	—	—	—	—	—	—	2·9	1·46	0·66
Watts per Square Inch	—	—	—	—	—	—	1·61	0·815	0·36

TABLE II.

30-TON CRANE. HANDLING 30 TONS.

	Lifting Motion.				Traversing Motion.				Travelling Motion.			
	H.P.	Time (secs.)	H.P. × Time.	H.P.² × Time.	H.P.	Time (secs.)	H.P. × Time.	H.P.² × Time.	H.P.	Time (secs.)	H.P. × Time.	H.P.² × Time.
1. Lifting...	13	144	1,872	24,336	—	—	—	—	—	—	—	—
2. Traversing	—	18	—	—	4	18	72	288	—	—	—	—
3. Travelling	—	52	—	—	—	—	—	—	15	52	780	11,700
4. Traversing	—	18	—	—	4	18	72	288	—	—	—	—
5. Lower	−6	120	−720	4,320	—	—	—	—	—	—	—	—
6. Taking Off Slings ...	—	30	—	—	—	—	—	—	—	—	—	—
7. Lift Hook	9·5	34	323	3,068·5	—	—	—	—	—	—	—	—
8. Travel Back	—	49	—	—	—	—	—	—	13	49	637	8,281
9. Lower Hook	8·5	34	289	2,456·5	—	—	—	—	—	—	—	—
	—	499	1,764	34,181	—	—	144	576	—	—	1,417	19,981

	External Load Factor.	Internal Load Factor.
Lifting Motor	$\frac{1,764}{15 \times 499} = 0{\cdot}234$	$\frac{34,181}{15^2 \times 499} = 0{\cdot}305$
Traverse Motor	$\frac{144}{4 \times 499} = 0{\cdot}072$	$\frac{576}{4^2 \times 499} = 0{\cdot}072$
Travelling Motor	$\frac{1,417}{15 \times 499} = 0{\cdot}188$	$\frac{19,981}{15^2 \times 499} = 0{\cdot}178$

TABLE III.

30-TON CRANE. HANDLING 15 TONS.

	Lifting Motion.				Traversing Motion.				Travelling Motion.			
	H.P.	Time (secs.)	H.P. × Time.	H.P.² × Time.	H.P.	Time (secs.)	H.P. × Time.	H.P.² × Time.	H.P.	Time. (secs.)	H.P. × Time.	H.P.² × Time.
1. Lifting...	15	64	960	14,400	—	—	—	—	—	—	—	—
2. Traversing	—	18	—	—	3·75	18	67·5	253	—	—	—	—
3. Travelling	—	52	—	—	—	—	—	—	14·5	52	754	10,933
4. Traverse	—	18	—	—	3·75	18	67·5	253	—	—	—	—
5. Lower	−6	54	−325	1,944	—	—	—	—	—	—	—	—
6. Taking off Slings ...	—	30	—	—	—	—	—	—	—	—	—	—
7. Lift Hook	9·5	34	325	3,068·5	—	—	—	—	—	—	—	—
8. Travel Back	—	49	—	—	—	—	—	—	13	49	637	8,281
9. Lower Hook ...	8·5	34	290	2,456·5	—	—	—	—	—	—	—	—
	—	353	1,250	21,869	—	—	135	506	—	—	1,391	19,214

	External Load Factor.	Internal Load Factor.
Lifting Motor	$\frac{1,250}{15 \times 353} = 0{\cdot}237$	$\frac{21,869}{15^2 \times 353} = 0{\cdot}275$
Traverse Motor	$\frac{135}{4 \times 353} = 0{\cdot}095$	$\frac{506}{4^2 \times 353} = 0{\cdot}089$
Travelling Motor	$\frac{1,391}{15 \times 353} = 0{\cdot}263$	$\frac{19,214}{15^2 \times 353} = 0{\cdot}242$

TABLE IV.

30-TON CRANE. HANDLING 5 TONS.

	Lifting Motion.				Traversing Motion.				Travelling Motion.			
	H.P.	Time (secs.)	H.P. × Time.	H.P.^{2} × Time.	H.P.	Time (secs.)	H.P. × Time.	H.P.^{2} × Time.	H.P.	Time (secs.)	H.P. × Time.	H.P.^{2} × Time.
1. Lifting	7·25	64	480	3,363·8	—	—	—	—	—	—	—	—
2. Traversing	—	18	—	—	3·5	18	63	220·5	—	—	—	—
3. Travelling	—	52	—	—	—	—	—	—	13	52	675	8,788
4. Traverse	—	18	—	—	3·5	18	63	220·5	—	—	—	—
5. Lower	0	61	0	0	—	—	—	—	—	—	—	—
6. Taking off Slings ...	—	30	—	—	—	—	—	—	—	—	—	—
7. Lift Hook	9·5	34	325	3,068·5	—	—	—	—	—	—	—	—
8. Travel Back	—	49	—	—	—	—	—	—	13	49	640	8,281
9. Lower Hook	8·5	34	290	2,456·5	—	—	—	—	—	—	—	—
	—	360	1,095	8,889	—	—	126	441	—	—	1,315	17,069

	External Load Factor.	Internal Load Factor.
Lifting Motor	$\frac{1,095}{15 \times 360} = 0{\cdot}202$	$\frac{8,889}{15^2 \times 360} = 0{\cdot}109$
Traverse Motor	$\frac{126}{4 \times 360} = 0{\cdot}087$	$\frac{441}{4^2 \times 360} = 0{\cdot}076$
Travelling Motor	$\frac{1,315}{15 \times 360} = 0{\cdot}243$	$\frac{17,069}{15^2 \times 360} = 0{\cdot}210$

DISCUSSION.

The Chairman.

The CHAIRMAN (Mr. W. M. Mordey, Vice-President): Mr. Hill has given us a practical and useful paper on a subject that is of increasing interest, and I will ask Mr. Alexander Siemens to open the discussion.

Mr. Siemens.

Mr. ALEXANDER SIEMENS: I would like especially to call your attention to one portion of the paper, which I will read out, because I desire to discuss it. The author says: "Some of the more common methods of specifying"—that is, the size of the crane motor—"are as follows:—

"(1) The H.P. required to lift or move the load, plus gearing losses, is taken as the B.H.P. of the motor. The motor is specified to be of this power, with a load factor of 20 per cent., 25 per cent., etc. (as the case may be), with continuous runs not exceeding, say, five minutes and temperature rise of 75° F. Thus a motor of 10 B.H.P. with 20 per cent. load factor, if worked intermittently at 10 B.H.P. with periods of rest four times as long as the periods of working, the latter in no case exceeding five minutes, would have a final mean temperature 75° F. above the atmosphere.

"(2) The H.P. required to lift or move the load, exclusive of gearing losses, is taken as the B.H.P. of the motor. The motor is specified to be of this power and to be capable of exerting double power for a few minutes.

"(3) The H.P. required to lift or move the load, plus gearing losses, is taken as the B.H.P. of the motor. It is specified to maintain this power on a continuous run of one hour with a rise of 75° F., and to maintain half this power for four hours with the same rise of temperature.

"(4) The H.P. required to lift or move the load, plus gearing losses, is taken as the B.H.P. of the motor. It is specified to maintain this power on a continuous run of $\frac{1}{4}$, $\frac{1}{2}$, or 1 hour, as the case may be, with a rise of temperature of 75° F."

What I want particularly to call attention to is the specification that motors running on intermittent loads should be rated by being run continuously for one hour at the rated H.P. That is manifestly not right. For one thing, the small motors arrive at their final temperature much sooner than the large ones. Therefore, if you run a small motor for one hour continuously, and call it an intermittent motor, you might just as well call it an ordinary motor that will do the same work for ever. On the other hand, a big motor will not attain its final temperature in the one hour, and may be far too large for the work. The whole subject has been treated in a very thorough way by Mr. Oelschläger in a paper published in the *Electrotechnische Zeitschrift* of December 20, 1900. Mr. Oelschläger there shows that the question of the size of an intermittent motor really depends on two factors: (1) The proportion of the time that the motor is doing work to the time that it is resting; and (2), the length of the time that it is doing work. In order to show the influence of the second factor, let me give you these figures. If you

Mr. Siemens.

have a machine which runs for one-and-a-half minutes and then stands for ten-and-a-half minutes, so that the total period is twelve minutes, we would call that a time factor of one-eighth. On the other hand there may be a machine which runs for two hours continuously and then stands for fourteen hours, so that the period is sixteen hours, but the time factor would there be also called one-eighth. That shows that you cannot go by the time factor alone; but you must put in your determinations the time that the motor is actually used. Mr. Hill has given us a number of equations to show how to calculate that out, and he also says that you have to add here a constant and there a constant, which have to be determined by experiment. But these formulæ, although they look so nice, are not really practicable. For instance, he brings in the surface of radiation, but the surface of the magnet inside the machine, where it is facing the other magnet, is not as good a radiator as the surface which is facing outward; and therefore you have to put in a lot of constants and factors to correct those diversities. Mr. Oelschläger has gone the other way round: he determined experimentally a large number of curves showing the increase in temperature with different loads, until the steady temperature is obtained. He also determined by experiment the curve of the motor for cooling.

After showing how these curves may be used to illustrate the changes in the temperature of a motor with an intermittent load, Mr. Oelschläger goes further, and deduces mathematically that the real critical constant that you want to know is what he calls the time constant (just the same as Mr. Hill), and which in reality is the time which the motor requires to reach 0·633 of its final temperature.

With the help of the time constant a number of curves can be constructed showing the heating of the motor, while the proportion between the period "a" that it is doing work, and the time constant (T) varies. As "a" diminishes, these curves become steeper, until at last you have a hyperbola in the case where "a" is infinitely small as compared to T. As a matter of fact this period T is several hours for most of the large motors; therefore the period "a" in crane work is so small that you need not trouble about any curves, except for the end curve—the limit curve, so to speak.

The principal object of my talking at such a length on this point is to impress upon you that it really makes a great deal of difference whether you select your motors by a test of one hour's continuous running under all conditions, or by tests graduated in accordance with the curve. In other words, Mr. Oelschläger comes to the same conclusion that Mr. Hill has come to, that you can substitute for a test of intermittent working a continuous run of a certain number of minutes' duration, and if the machine does not attain the forbidden temperature during that run of so many minutes, neither will it attain it in the intermittent work for which it is destined.

The following table gives these values for one type of standard motors manufactured by my firm for crane work:—

Mr. Siemens.

TIMES IN MINUTES AT HORSE-POWERS STATED TO REACH 80° F. RISE WITH EQUIVALENT TIME FACTOR RATING GIVEN OVER EACH COLUMN.

TYPE.	1/8		1/6		1/4		1/3		1/2	
Medium speed.	Min.	H.P.	Min.	H.P.	Min.	H.P.	Min.	H.P.	Min.	H.P.
6-C.	15	7	20	6½	30	5¼	40	4½	60	3½
8-C.	15	11	20	9	30	7	40	5½	60	4
9¾-C.	18	15½	25	13½	37	11	50	9	75	7
11-C.	22	23	30	20	45	16	60	13	90	10
13-C.	26	35	35	30	52	24	70	20	105	14
15·1-C.	30	50	40	43	60	33	80	27	120	20
15·2-C.	30	74	40	60	60	48	80	39	120	25

From the figures given in the table it appears that in making a one-hour test you may sometimes select a machine which is too small and sometimes a machine which is too large. But this method elaborated by Mr. Oelschläger and also by Mr. Hill will do all that you require to select the right size of motor for intermittent loads.

Mr. Bate.

Mr. A. H. BATE: The paper is an exceedingly interesting one to all using or manufacturing motors for intermittent work, and I think it is of great interest for other purposes besides cranes, although Mr. Hill has confined himself in the title of the paper to that subject. The overload temperatures that are given in Table I. are very interesting, and it would be instructive to know how Mr. Hill obtained them. Were they calculated from some assumed data, or were they the results of experiments? Some experiments that have been made with the armatures stationary, by simply passing excessive currents through, up to ten and fifteen thousand amperes per square inch, give very much smaller rises of temperature than Mr. Hill has stated here. Then, in applying those overload figures to cranes, I cannot quite see that they are so applicable to cranes as they are to some other purposes, because in the ordinary way one specifies the horse-power of the motor as the power required to lift the load at the specified speed with the full load of the crane, and therefore unless something goes wrong with the gearing, such as the brake magnet failing partially and allowing the brake shoes to come down, or something like that, I do not see how the crane motor is liable to overloads. But in the case of motors driving machine tools, where one is always subject to very heavy overloads, then these figures are of extreme importance if we can really rely on them.

Aitken.

Mr. JAMES AITKEN: On page 9 of the paper, just after the diagram, Mr. Hill says: "It has been generally noted among crane-makers that quarter-hour rated motors have a habit of burning out with a facility which has been somewhat surprising to them." Speaking from the user's point of view rather than the electrician's, I would say that the maker of the crane seldom knows the exact work that the crane has to

do, and seldom realises the enormous overloads that are placed on the crane in an ordinary day's work. It is no use telling the owner of the crane that it is not having fair play. He will turn round and say, "I want the crane to do my work; if it won't do it, take it away." With regard to the best voltages for crane and direct driving motors for engineers' tools, I should like to hear Mr. Hill's views on this subject. I had rather a curious experience a few months ago. I was visiting an engineering works which is electrically driven; the voltage was 220, but they have now reduced it to 110. The reason I got for this was that with 100 volts, if a fault developed, it lasted, say, a fortnight before anything serious happened, which gave time to have it attended to. With 220 volts the fault became serious in a week. "What about 500 volts?" I asked. "Oh, there are fireworks before you know what has happened!" There is certainly something in this. Again, from a mechanical point of view, with high voltages the wires are so fine and connections to the commutator so light that there is always present the liability of breakages. With low voltages a good mechanical job can be made. I should also like to hear Mr. Hill's views on the length of life of crane and other similar motors. My experience puts this at about seven to eight years. As previously stated, I speak from the user's point of view, and the user certainly deserves some consideration. Mr. Aitken.

Mr. W. Stokes: To my mind Mr. Hill's paper is an exceedingly useful one, particularly from my own point of view, which is that of a crane-maker. The rating of ordinary crane motor manufacturers is very indefinite. That a motor will rise to a certain temperature after half an hour's working at full load is no information at all, apart from experience in previous instances of the same make of motor. Messrs. Siemens Bros., however, have a much better system. Their system is the most scientific and the best adapted for the requirements of the crane-maker that I have ever come across. The unit is twelve minutes; the motor works for three minutes and stands nine minutes at one-quarter load factor, or six minutes on and six minutes off at a half load factor, and they tell you what a certain size of motor will do on this basis. They say that a certain size will develop 9 H.P. at third load factor, 10½ H.P. at one-quarter load factor, and so on through the series. With these figures before you, the motor which is best suited to the crane to be considered can be chosen at once. But the number of starts and stops has also to be kept well in mind. Each crane has its own particular duty; for instance, a crane lifting through 40 ft. should have a different motor from one lifting 5 ft. or 6 ft. In these days of keen competition, when one has to get orders on price, it is necessary to put in a motor which is as cheap as possible, and yet which will work satisfactorily; and I venture to hope that now that Mr. Hill's paper has drawn attention to this method of calculating, motor-makers will give the information which is really useful and definite. I have in vain asked motor-manufacturers how long it will take for one of their motors to cool down again after it has risen to the specified temperature, but in all cases they either cannot or will not give this information. There Mr. Stokes.

Mr. Stokes. is another matter which Mr. Hill has not touched upon which I think is very seldom borne in mind; that is what may be called the "driver factor." It seems to be the idea nowadays that almost anybody who is a handy man can drive an electric crane. The result is the man after a time, finding that nothing serious happens beyond a blown fuse or two (which can be got over by using two or three wires instead of one !), gets into the habit of turning the controller handle round to full speed without a pause, and even reversing with the motor still running. That is not what Mr. Hill calculates upon, nor what the motor-manufacturer expects. The result is that although the motor may be very suitable for the work with reasonable handling, it may fail under this kind of treatment. A very large margin of safety should be allowed for the rushes of current at starting, and, although we have very scientific methods of calculation, I think that in the end it is more prudent to allow a very wide margin of safety. To my mind this is really the only safe way. I am afraid it is not the way to get orders on price, but it is the right thing to do. I would give as an instance of this unexpected treatment of motors a case with which Mr. Hill is familiar. We constructed an apparatus which had to run at several definite speeds and we had a great many consultations as to the number of steps in the controllers which were required, so that the motors should not be unfairly treated. These steps were duly provided, and the trial run went off very satisfactorily, and we—the makers—retired. Some few months afterwards I had occasion to go to this place in order to see what was going on. I should have said that we had a sort of emergency arrangement, so that the current could be cut off instantly without putting the controller round, as the controller worked rather slowly, being a very large one and operated by worm gear. I found that instead of turning the controller handle round slowly to get the various speeds by steps, the driver wound the controller round to the desired speed with the current off, and then, at the requisite moment, on went the current by means of the emergency switch, and the steps which we had taken so much trouble to provide were all thrown away. I mention this case to show that, although one may design a thing with the best intentions, the treatment it will get in practice is so very different, that multiplying by two is, in the end, a very necessary precaution.

It has always struck me that there is an opening for a more scientific treatment of the cooling arrangements in motors. The colour, texture, and extent of surface have such an effect on the dispersion of the heat, that it would appear that if a motor-manufacturer wants to cut his motor down to the smallest size with the biggest H.P., he should turn his attention in this direction.

Mr. Hill's formulæ are very useful to the motor-maker, but without the constants found to apply to each design and type, it is still impossible for the purchaser to transform half-hour rating into equivalent intermittent short-period working.

Mr. Davis. Mr. F. W. Davis (*communicated by Mr. F. E. Elmore*): I think we are very much indebted to Mr. Hill for the very clear and careful way in which he has described to us the best method of employing crane motors

and controllers. As I have had some experience with the use of shunt motors and speed controllers described by Mr. Hill, I can say that I think the system marks a distinct step in advance in this class of work; especially would this be the case in cranes which have to lower their loads for a considerable distance. On the New High Level Bridge at Newcastle I had a shunt motor and controller on a 5-ton derrick crane with a 70-foot jib, and the same system on a 15-ton Goliath travelling crane. In our girder works at Darlington it has been used on a 30-ton overhead crane for nearly three years and has been very satisfactory. The work of the driver is much simplified, and he has complete control over the load without having to use a brake as a means of slowing it down, this being the usual practice with series motors. The 5-ton derrick has been used constantly for setting granite ashlar in position, and this fact shows that the control over the speed of lifting and lowering is perfect. The acceleration was also found to be much steadier than with the other cranes with which we had series motors. Mr. Davis.

One important factor to be borne in mind, especially with large cranes which are erected at a great height from the ground, is safety in working, and I think that this system, with an electric brake to act in case of the current or fuse failing, makes the working of the crane perfectly safe, as it is impossible for the crane to run away, or, what is more important still, for the jib to run away when being lowered. I am sorry that we did not adopt the same system on the large 10-ton Blondin which we erected over the river, as in lowering loads with this we had a large amount of trouble with the brakes, which were constantly getting too hot. Loads of eight tons had to be constantly lowered for the distance of 120 feet, and with a shunt motor system we should have effected a very considerable saving by returning the current to the main circuit while loads were being lowered.

Mr. C. W. HILL (*in reply*): I have not read the paper by Oelschläger to which Mr. Siemens has referred, and which appears to treat the subject of intermittent working in a broad and general manner. My paper being on crane motors, I specially confined myself to dealing with machines having short working periods, and having, in fact, load factor curves as shown in Fig. 23. As Mr. Siemens says, the formulæ which I have given will not make it possible to calculate the temperatures, times of running and load factors for crane motors unless the values of T and C have been determined experimentally from previous machines, but this is also the case with the formulæ given by Mr. Oelschläger. When these values have been experimentally determined from two or three machines of a given type, the temperature curves, etc., of other machines of the same type, but of different size, may be predetermined fairly accurately. Mr. Hill.

In making the calculations, we may either take a given size of machine, and find the temperature which will be attained with a given load factor, or we may reverse the process, and, starting with a definite temperature and load factor, find the size of machine necessary. The latter process is the one which I prefer.

Mr. Hill. With regard to Mr. Bate's remarks, the temperatures shown on Table I. are calculated temperatures, and they are calculated on the assumption that the overload would last for such a short time that the whole of the heat generated would be confined to the armature winding. If the overload lasted for any length of time, the heat would spread and the rate of rise would be less. The case of motors driving machine tools is rather different to that of motors driving cranes. A motor to drive a machine tool is put down to run continuously, and may have to drive the tool all day long with a fairly steady load on it; so that the motor which is driving a machine tool is practically running with a load factor of unity, and, as we may see from the curves in Fig. 23, it is, or should be, capable for short periods of carrying a considerably greater load than that which it takes when driving the tool in the ordinary way. But a crane motor is an overloaded motor to begin with, and if you further overload it, its temperature naturally rises very rapidly.

The question of voltages was referred to by Mr. Aitken, and I may say that, so far as outdoor contract work is concerned, it does not seem altogether advisable to go beyond 220 volts if one can help it, because we cannot prevent earths on the circuits, and shocks from more than 220 volts may lead to serious accidents.

In reply to Mr. Stokes's remarks, he complains that motor-makers specify a continuous run of half an hour or an hour, and he says that does not give him any indication of what the motor can do when he is driving the crane. That is exactly the object of my paper, to be able to combine the two things, so that when Mr. Stokes tells us what he wants the motor to do, we can give him a motor to work on a definite load factor, and at the same time we can, for the convenience of the motor-makers, make a continuous run at full load for testing purposes, and be sure that the effect obtained on the continuous run will be the same as that obtained when driving the crane in the usual way.

Since the meeting, Mr. Siemens has been kind enough to show me a copy of Mr. Oelschläger's very interesting paper. There is one point which neither Mr. Oelschläger nor any other investigator (so far as I can discover) has taken into account, and that is the effect of starting currents. They all assume that during each working period the machine works at its rated H.P. only, and no account is taken of the fact that each time the motor starts the current for a time exceeds the normal. By reference to Figs. 11, 12, and 23, it will be seen that the load factor corresponding to a given time run decreases as the starting currents are increased. This is an important point to bear in mind when settling the size of motor for any particular job. I agree entirely with Mr. Siemens that it is impossible to obtain satisfactory results by adopting a uniform time rating for all sizes of crane motors. As the time constant increases with the size of machine, the length of continuous run corresponding to a given load factor also increases with the size of machine. With further reference to Mr. Bate's remarks, the methods which I have described for calculating crane

motors would not be applicable to motors driving machine tools. The graphic method is, I think, in this case preferable. If templates are cut out for the cooling curve, and for the heating curves corresponding to different loads, these templates may be used in the same way as set squares, in conjunction with a T square, and complete temperature diagrams of, say, a day's working can be laid out, and the amount and duration of overloads which may be allowed without exceeding the permissible limits of temperature can be ascertained. Mr. Hill.

The CHAIRMAN: As there is no one to call me to order, I would like to make one or two small remarks. I think this paper deals, at least by inference, entirely with direct-current motors. I wish the author had said something about the alternate-current motors that are now very often used on cranes. Many of us have to put in motors where there is nothing but alternate current, and it is just as well we should remember that we can drive cranes in that way. It is, of course, only a branch of the great subject of electrical traction. The Chairman.

I will now ask you to accord to the author a very hearty vote of thanks for the exceedingly useful paper that he, as a specialist in his subject, has given us to-night.

The resolution was carried with acclamation.

The meeting adjourned at 9.20 p.m.

Proceedings of the Four Hundred and Thirty-seventh Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 8, 1906 — Mr. JOHN GAVEY, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on February 22, 1906, were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members—

John Owen Girdlestone.

From the class of Associates to that of Members—

Percy Gilbert Ledger.

From the class of Associates to that of Associate Members—

George Conrad Blair.

From the class of Students to that of Associate Members—

Herbert Dudley Ash
Charles Fitzroy Farlow
Claude N. Macdermott.
Edgar L. Smith.

Messrs. C. J. Jewell and A. R. Munro were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Edward W. Arnold.
Frank Shepherd Ashton.
Robert Bilsland, B.Sc.
Joseph Henry Dobson.
Ernest William W. Durham.
William Vincent Edwards.
Gerard Graham.
Alfred Heinrich Kelsall.
David Morgan Kinghorn.
John Lithgoe.
William Slater Naylor.
John Steel Nicholson, B.Sc.
Alfred Rider.
Edward Salthouse.

As Students.

Frank Cedric Dannatt.	John Harold Odam.
Charles Bruce Gardner.	Richard De Fontaine Stratton.
Andrew Hamilton.	Frank Stroude.
Joseph Sargon Lazarus.	Lynar Frederick Summers.
John Finlay Lochhead.	Colwyn Griffiths Thomas.
Edward William Murray.	Charles R. Wrigley.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. E. Arnold, The Birmingham and Midland Institute Scientific Society, The Departmental Committee on the Royal College of Science, Gauthier-Villars, The Italian Minister of Posts and Telegraphs, C. Kinzbrunner, Dr. St. Lindeck, T. Commerford Martin; to the *Building Fund* from Messrs. P. F. Crinks, J. Eck, S. S. Grant, A. P. Pyne, L. C. B. Trimnell; and to the *Benevolent Fund* from J. Gilligan, to whom the thanks of the meeting were duly accorded.

The meeting adjourned at 9.30 p.m.

The following paper was read and discussed:

A NEW SINGLE-PHASE COMMUTATOR MOTOR.

By V. A. FYNN, Member.

(*Paper read March* 8, 1906.)

During the last few years quite a number of engineers have been engaged in an attempt to produce a single-phase motor which could compare with its continuous-current rival. As the railway problem has been principally in mind, these efforts have been restricted to types possessing a series characteristic, and consequently to motors unsuitable for most of the stationary work. There exists, however, a great demand for a "constant speed" machine, with great starting torque and high power factor. The motor to be described in this paper can be built with either shunt or series characteristic; the former class has now been fully developed.

It was in 1897 that the author first designed a motor with high starting torque, and high power factor at practically constant speed; but although full working drawings were prepared, various circumstances prevented a practical test of the ideas embodied in its design. Five years later a machine was at last put in hand and executed to the original drawings, and the first patents were applied for; but although the results of the very first tests were most encouraging, lack of support and capital again delayed the development of the new motor. A whole series of these machines has, however, now been carefully worked out; in principle these are identical with the original type; but many improvements have been added in the course of exhaustive tests carried out by the author.

Several forms of single-phase commutator motors have been described during the last year or so in the technical press, and some of these have been subjected to practical tests; the designers of all of them, including the author, owe a heavy debt of gratitude to the early workers. It would lead too far to make even an attempt to do justice to all those who contributed to the development of monophase motors in early days, but no description of a modern single-phase commutator motor can be complete without a reference to the pioneer work of Mr. Ll. B. Atkinson, who, in a masterly paper read in 1898 before the Institution of Civil Engineers,* described those forms from which all the modern single-phase commutator motors are directly derived, and who already then dwelt at length on their several advantages and peculiarities.

* *Minutes of Proc. of Institution of Civil Engineers*, vol. 133, page 113.

When the asynchronous single-phase motor was accidentally discovered, somewhere about the year 1890, inventors were faced with the difficult problem of bringing such machines up to speed. A device proposed at the time by several investigators independently, consisted in starting the motor as a "repulsion machine," and when a sufficient speed had been reached, converting the machine into an asynchronous motor by short-circuiting a part or the whole of the commutator, or by closing several points of the armature or rotor winding through resistances, by means of slip-rings or the like.

The author at that time had the advantage of being employed by Mr. C. E. L. Brown, a very early worker in this field, and carried out quite a number of tests on such machines for him. The properties of such motors were then fully understood and appreciated; but the extreme simplicity of the motor with squirrel-cage rotor had taken such a hold of everybody's mind that the bare mention of a commutator in connection with an alternating-current motor discounted its commercial value. Then, again, in those days we knew much less about commutation than we do at present, and we had not at our disposal the good carbon brushes we now have, nor the necessary experience in building up commutators. The sparking difficulties, which under existing circumstances still require the most serious attention in order to be successfully overcome, presented insurmountable difficulties in those early days; and although many tests were made on series, "repulsion," and combined "repulsion-induction" motors, very few of these machines ever left the test-room. Finally, all attempts in that direction were definitely abandoned, and the whole attention, not only of Messrs. Brown, Boveri & Co., but of other leading firms, concentrated on the development of the polyphase motor.

A consideration of the fundamental form of the single-phase induction motor, as defined by Atkinson, will help best to the full understanding of the new motor designed by the author, more particularly in its constant speed form. The Atkinson motor is shown diagrammatically in Fig. 1. The primary member is magnetised along an axis F by means of the winding S. The secondary member, which consists of an armature provided with a continuous-current winding connected to a commutator, is short-circuited by means of the brushes CC and DD along two perpendicular axes, one of which coincides with the field axis of the primary member or stator. This diagram and all the following ones represent 2-pole machines, while throughout the armature winding is supposed to be of the Gramme-ring type, with the brushes bearing directly on the armature winding; and hence the axis of a field which could be set up in the rotor by a current passing a set of brushes will coincide with the axis of that particular brush set.

Such a commutator motor has all the characteristics of the asynchronous single-phase squirrel-cage motor; in fact, the latter is only a special case of the former. It is easy to see that two axes is the smallest number along which such a rotor can be short-circuited in order to work at all; any further increase in the number of short-circuits

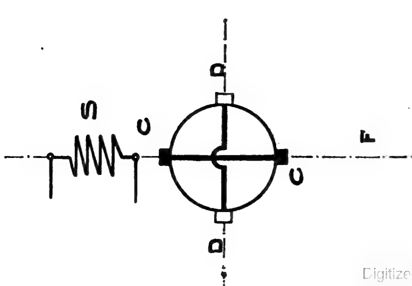


FIG. 1

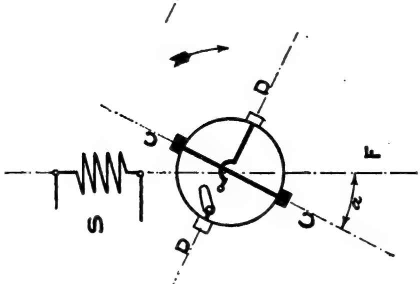


FIG. 2.

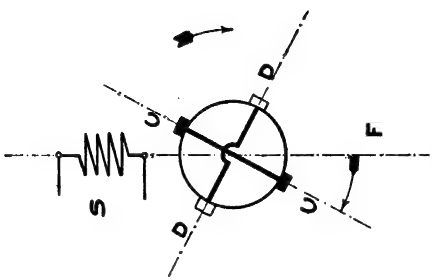


FIG. 3.

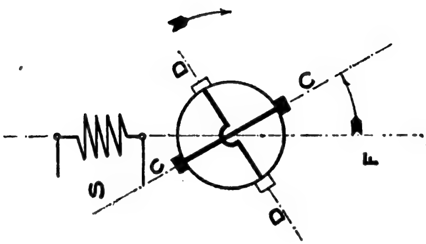


FIG. 4.

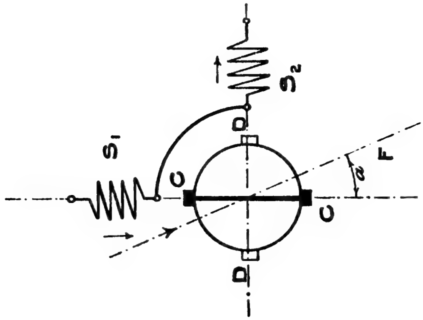


FIG. 5.

does not alter the nature of the motor. Thus, instead of what might be termed the 2-phase short-circuiting arrangement shown in Fig. 1, a three or four or more phase short-circuiting arrangement could be used with the same result. If the number of short-circuits is chosen so high that the whole of the commutator is covered by brushes, in other words, so that the whole of the commutator is short-circuited, then the latter can obviously be done away with and its place can be taken by a continuous ring. We thus arrive at the simple form of the rotor known as the squirrel-cage.

The motor in Fig. 1 will not start; if brought up to speed artificially it will do useful work running somewhat below synchronism, but its power factor is bad, it is very liable to spark at the commutator, and its output for a given weight is small. It is probably on account of these inherent defects that this motor never came on the market.

Early recognising the possibilities of this type of motor, the author subsequently set himself the problem of evolving from it a new motor, in which the above defects would be, as far as possible, eliminated; and although the several improvements effected have been spread over a number of years, it is claimed that this problem may now be considered as having been satisfactorily solved, and a really commercial commutator motor evolved from the fundamental type. The presence of the commutator at once suggests the possibility of starting such a machine as a shunt, a series, or a "repulsion motor," and of phase compensation, but the shunt arrangement for starting must be at once discarded, since it is only at very low speeds that the motor will develop a good torque under those conditions, while plain-series connection also gives comparatively poor results. On the other hand, the machine starts very well as a "repulsion motor."

It is feared that the term "repulsion motor," which has already been used repeatedly in this paper, may lead to some misunderstanding. As far as could be ascertained this term is now generally applied to a machine mainly consisting of two members which are disposed in such a way that the one can rotate with respect to the other, and where the secondary member is short-circuited along a fixed axis not coinciding with the axis of the field produced by the primary member. It is further generally stated that the speed and torque of such a motor is, for equal conditions, entirely dependent on the angle enclosed between the axis along which the secondary member is short-circuited, and the field axis of the primary member.

In Fig. 8 is shown one form of such a "repulsion motor." The secondary member is here the rotor, which is short-circuited along a fixed axis by means of the brushes C C. The primary member is here the stator, and carries the winding S which produces the field with the axis F. The axis along which the secondary member is short-circuited is displaced by α degrees with respect to F. It is, we believe, fairly well understood how the magnitude of α affects the general performance of the motor, but we are afraid that the operation of the motor is often attributed to some peculiar repulsive effect between the short-

circuited rotor and the stator field such as was discovered by Elihu Thomson in 1887, and made use of by him in the construction of his motor.

Now the term "repulsion motor," although thoroughly justified when applied to Elihu Thomson's original motor (American Patent No. 363,165), is an entirely unsuitable designation for that type of motor to which it is applied nowadays. This confusion probably arose out of a misapprehension as to the true principles underlying the operation of machines such as are diagrammatically represented in Figs. 5 and 8. These machines do not depend for their operation on Thomson's repulsion effect between a short-circuited coil on the rotor and the primary field. In fact, the Thomson effect in these machines is, particularly at starting, directly responsible for a negative torque which can reach extremely high values in a bad design, and which is due to the current in those coils which are short-circuited under the brushes.

We think it is much more correct to consider such motors as being "series induction machines;" it is a more ponderous denomination than the well-established term "repulsion motor," but it is at least correct and will avoid confusion, more particularly as true repulsion motors as originated by Elihu Thomson are, we believe, still made use of. That the motors shown in Figs. 5 and 8 are true series induction machines can be easily established, and the author will take this opportunity of briefly stating what he believes to be the true theory of these machines.

First turning our attention to the arrangement shown in Fig. 5, we have a stator winding divided into two groups, S_1 and S_2, connected in series and displaced by $\frac{180}{n}$ degrees with regard to each other (n stands throughout for the number of poles of the machine). The axis of the group S_1 coincides with the axis along which the rotor is short-circuited. In this axis C C we have all the conditions of a transformer, the rotor representing the secondary and the stator group S_1 representing the primary. It follows that under all conditions the rotor current will be (omitting sign) very nearly in phase with the current in both stator groups, since they are in series. The field in the axis of S_1, and to which we will refer as the transformer field, is due to the magnetising component of the transformer no-load current; the latter is represented in phase and magnitude by the resultant of the primary and secondary currents. The field in the axis of S_2 is due to the total current flowing through the stator, and is in phase with it, consequently very nearly in phase with the rotor current. This second field induces no current in the rotor, but, with the rotor current induced along the transformer axis, which is perpendicular to the axis of this second field, it produces the motor torque, and hence we will refer to this second field as the motor field. We therefore have here precisely the same conditions as exist in the series conduction motor, except that in the present case the current is not conveyed into the rotor by conduction, but by induction. The direction of rotation is in both types of motor determined by the same rules, and the torque is due to the same causes.

Turning now to Fig. 8, it is easy to see that the conditions there are

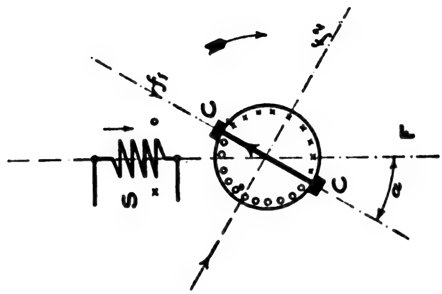


FIG. 8.

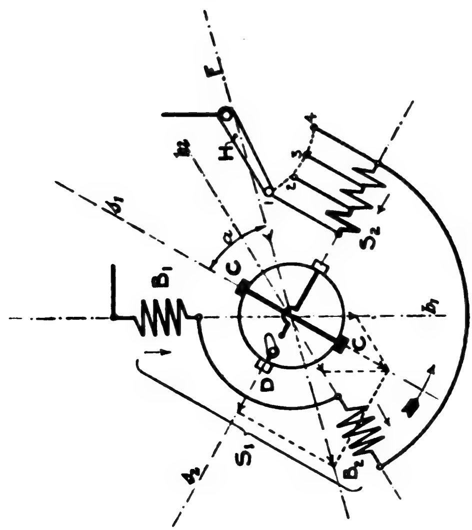


FIG. 7.

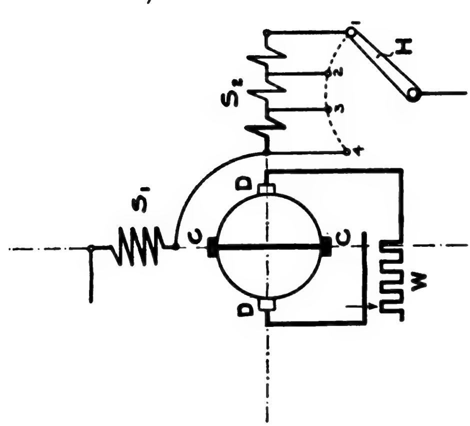


FIG. 6.

the same. The field with the axis F produced by the winding S really resolves itself into two components, one of which, f_1, coincides with the axis along which the rotor is short-circuited, and represents the transformer field; whereas the other, f_2, is displaced by $\frac{180}{n}$ degrees with regard to the former, and represents the motor field. It can be said that in Fig. 8 the stator winding directly produces the resultant F of the transformer field f_1, and the motor field f_2, whereas in Fig. 5 the stator windings each produce one of the components (transformer field in the axis C C, and motor field in the axis D D) of the resultant field F. In Fig. 8 the phase, magnitude, and direction of the resultant F are fixed by the stator winding; the phase, magnitude, and direction of the transformer and motor field are, roughly speaking, determined by the position occupied by the axis along which the rotor is short-circuited with respect to F. In Fig. 5 the phase, magnitude, and direction of the two component fields are determined by S_1 and S_2 respectively, and they determine the phase, magnitude, and direction of the resultant F. Considering more closely the conditions prevailing in Fig. 5, we see that the phase relation between the transformer and the motor field is a variable one. When at rest, the conditions in the axis C C are those of a short-circuited transformer, and in consequence the resultant current in the primary S_1 will lag very considerably behind the E.M.F. impressed on the stator, and will therefore tend to approach the phase of the transformer field, which lags by practically 90 degrees behind that E.M.F. The current in S_1, when taken through S_2, sets up the motor field in the axis D D, the phase of which practically coincides with the phase of the current producing it. Now the phase of that current will vary with respect to the phase of the transformer field, very much as the power factor of the motor varies, with the result that the phase of the motor field will also vary with respect to the phase of the transformer field.

When the motor begins to move, an E.M.F. due to rotation of the rotor conductors in the motor field is set up in the rotor along the transformer axis; in phase, this E.M.F. coincides with the phase of the motor field, and tends to oppose the E.M.F. impressed on the rotor (by induction) in the transformer axis. This last E.M.F., which we will call E T, is, omitting sign, in phase with the E.M.F. impressed on the stator, and corresponds to the working E.M.F. impressed by conduction on the armature of an ordinary continuous-current motor; the E.M.F. due to rotation and tending to oppose E T corresponds to the back E.M.F. in a continuous-current motor, and we will refer to it as E B. As the motor gathers speed, the conditions in the C C axis, to which we can also refer as the armature axis, approach more nearly those prevailing in a transformer working on a circuit possessed of a small amount of self-induction, and the phase of the current in S_1 will approach more closely to the phase of the E.M.F. impressed on the stator. The current in the armature axis is determined by E W, an E.M.F. which goes to cover the C^2R loss in the rotor, and which is the resultant of E T, E B, and E S, the latter being the E.M.F. of self-induction, and principally

due to the leakage between secondary and primary in the transformer axis. It will be observed that we have here conditions quite similar to those obtaining in single-phase induction motors, or single-phase shunt induction motors, as the author prefers to designate them. The theory of these motors has been fully set forth by him in an article published recently.

The speed of the series induction motor for a given torque will fall until the resultant of E T, E B, and E S can produce in the armature axis a current of sufficient magnitude to yield the torque required in conjunction with the motor field then available. That current for a given field strength will be the greater, the greater the phase difference between itself and the motor field. The phase of the armature or rotor current will depend on the phase and magnitude of E B and on the magnitude of E S, which is proportional to the rotor current. The phase of E B depends indirectly on the phase of the stator current; its magnitude depends on the motor field strength and the speed of rotation. The strength of the motor field depends, as has already been pointed out, on the stator current, and this last condition imparts to the motor its series characteristic. Taking an ideal motor of this type where the transformer field is quite in quadrature with the motor field, where E S is zero and where there are no losses, then, for a given torque, the speed will fall until the difference E T–E B is reduced to just that value which will suffice to drive through the rotor a current of such magnitude as will produce with the motor field then available the required torque. The field available depends, as is well understood, on the number of turns in the field winding and the magnitude of the current flowing through them as long as the densities are not too high.

It is seen that these conditions are identical with those of an ideal continuous-current motor, and only very little different from those of a commercial motor of this class. An ordinary commercial single-phase series induction motor will, however, run very much slower than a corresponding continuous-current motor operated under exactly similar conditions, and that on account of the phase difference existing between the armature current and the motor field, which makes a larger armature current necessary to produce the torque required with a given field, and consequently calls for a smaller E B and a correspondingly lower speed.

The angle a is to a certain extent a guide to the performance of the machine; thus the greater a in Fig. 8, the smaller f_1 (the transformer field), and the smaller E T, but at the same time the greater f_2 (the motor field), consequently the lower the speed at which E B will nearly equal E T. Since with increasing a the E.M.F. impressed on the armature axis decreases, whilst the number of turns and the resistance of the rotor remain constant, the output of the machine must also decrease. When a equals 90 degrees the motor field becomes a maximum, but there is no E.M.F. impressed on the armature, and the motor cannot exert any torque. If, on the other hand, a is continually decreased, the power of the motor, after reaching a

maximum, finally again becomes nil when a is zero, because then there is only a transformer field and no motor field. If a is now increased in the opposite direction the motor will also start in the opposite direction, because, whilst the direction of the transformer field, and with it the direction of the armature current, has remained unchanged, that of the motor field in respect to it has been reversed. In the case of Fig. 5, and as a rough approximation, one could say that the ampere turns in S_2, divided by the magnetising ampere turns in S_1, were equal to a, or, as a very rough approximation, one could take the proportion of the ampere turns in S_2 to the ampere turns in S_1.

We can now proceed with the description of the motor under consideration. It has been said that it starts best as a series induction machine, and consequently it is started as such. Now that we have stated what we consider to be the true theory of these series induction machines it will be possible, without fear of confusion, to materially shorten that part of the description relating to the starting performance of the motor in question.

The machine shown in Fig. 1 can be started as a series induction motor by opening one of the rotor short-circuits, say D D, and displacing the whole brush system in such a way that the brushes C C will short-circuit the rotor along an axis forming an angle a with the axis of the stator field as in Fig. 2. After a sufficient speed has been attained the brushes D D may be short-circuited, and under these conditions the motor will operate as a shunt induction motor, but that component of the field produced by the stator which falls in the direction D D of the motor field will have a disturbing effect on the operation of the motor, because the phase of that component will not be the same as the phase of the motor field produced by the current flowing in the D D circuit.

A shunt induction motor, having its rotor short-circuited along two perpendicular axes, operates best when the axis of one of the short-circuits coincides with the stator field axis. If, for instance, a motor of this kind is running in a clockwise direction, and the brush system is displaced *in* the direction of rotation as shown in Fig. 3, then the current in the D circuit will fall off while that in the C circuit will rise, the line pressure and the load on the motor remaining constant; on the other hand, if the brush system is displaced in a direction *opposed* to that of rotation, as in Fig. 4, then the current in the D circuit will rise while that in the C circuit will fall.

In the first case the component of the stator field coinciding with the motor field axis tends to strengthen the motor field, which accounts for the decrease in the current in the D D circuit, but at the same time it increases the phase difference between the motor field and the armature current in the axis C C, hence the increase of current in that axis for the same torque. In the second case this component is of the opposite direction, and tends to weaken the motor field, hence the increased current in the D D circuit; at the same time it brings the phase of the motor field into closer coincidence with the phase of the armature current, hence the decrease of the C C current. Either condition is

detrimental to the working of the motor, and of the two the former gives the worst results.

The direction in which such a motor will start depends on the direction in which the short-circuited brushes C C are displaced from their original position of coincidence with the stator field axis; and, with a constant voltage at the terminals, the torque obtained and the current taken depend on the amount of that displacement; but it is obvious that the brush system could not be displaced at all in any commercial machine.

The disposition shown in Fig. 5 allows of the direction of rotation being reversed by reversing the current either through S_1 or S_2, but there is no provision for regulating the starting current or the torque, and when the motor has been brought up to speed it shows the same disadvantages as have already been pointed out in connection with Fig. 3. The author, by suitably modifying the disposition shown in Fig. 5, gets over all these difficulties simply and effectively. The improved arrangement is shown in Fig. 6; it makes it possible to reduce the current taken by the motor, when switched on to the mains, to any desired amount, and it allows of this motor being gradually started and brought up to its normal speed without the use of the usual resistances, transformers, or the like; all that is necessary is a switch such as shown at H connected to the various tappings provided in the group S_2. With the help of this same switch, the group S_2 can be finally switched out altogether, thus enabling the motor, after it has been converted into a shunt induction machine, to work under the most advantageous conditions, current being supplied to the group S_1 only.

With this end in view the number of turns in the group S_1 is so chosen as to secure the required flux densities under normal terminal pressure, and the cross section of the conductors in this group is determined by full-load conditions. The total number of turns in the group S_2 is determined by the permissible current on the first notch of the starting switch, and the smaller this current is to be, the greater must be the number of turns in S_2.

A comparatively small number of turns in the S_2 group will be sufficient in most cases, since an increase in the number of these turns not only reduces E T, the E.M.F. impressed on the armature, and consequently the short-circuit current, but also increases the total number of turns in series across the mains, and consequently the total impedance of the motor; this rises the quicker because the turns of that group are increased which possesses the greater self-induction. With the same number of tūrns in both groups, a motor of this type will start light with somewhat less than its no-load current.

The group S_1 provides the transformer field, whereas the motor field is excited by the group S_2, the motor starts as a series induction motor and the greatest torque is secured with the (D or) field brushes on open circuit; were they short-circuited from the very first, this short-circuit in the motor field axis would necessarily alter the phase of the motor field and bring it into nearer coincidence with the transformer

field, thus increasing the phase discrepancy between the armature current (axis C C) and the motor field, and greatly reducing the torque. As the speed increases, this D circuit can be closed over resistances and these can be gradually cut out, the motor acquiring by degrees the characteristics of what is known as the asynchronous induction motor. If care is taken to close the D circuit at about synchronous speed, the resistances can be dispensed with, and they are not provided with the small motors. Although the motor is now running at practically normal speed, it will only be able to give little power if part of the group S_2 is still in circuit, owing to the weakening effect of this S_2 winding under these circumstances, and also because the densities in motor will be below the normal.

In order to gradually bring about the more advantageous conditions of Fig. 1, and to raise the densities to their normal value, the lever H is gradually moved further and further until the whole of the S_2 winding is cut out. A certain amount of speed regulation, however, can be secured by including more or less of the S_2 winding in the motor circuit and still leaving the D brushes short-circuited.

The conductors of the S_2 group, when the latter is used only for starting, can have a comparatively small cross section. But when this winding is also to be used for speed regulation, the conductors will require to be larger.

The stator winding can also be arranged in three divisions on the lines of the ordinary 3-phase winding, if this is a manufacturing convenience, as shown in Fig. 8. The three divisions B_1, B_2, and S_2 are displaced by $\frac{4}{3} \cdot \frac{180}{n}$ degrees. The divisions B_1, B_2 (forming together the group S_1) each set up a field, the respective axes of which are b_1 and b_2, while the division S_2 produces a field along the axis s_2. The two former combine according to the parallelogram of forces to form the resultant field s_1, which is necessarily perpendicular to s_2; the actual fields are shown by dotted lines in Fig. 7. If we now place the brushes C C coaxially with s_1, we arrive at a disposition that is equivalent to that in Fig. 6, and it is only necessary to provide the third division S_2 with the required tappings 1, 2, 3, and 4 in order to be able to regulate the starting torque or the speed of the motor.

A new, simple, and effective method of starting and regulating such motors has now been described, which can of course be equally well applied to the starting and regulating of any ordinary series induction motor; but the motor as it now stands still has a bad power factor and a small output for a given weight, and is still liable to spark.

Before describing the means adopted to improve the power factor and the weight efficiency of the motor, it will be best to set forth shortly the working theory of such machines when running at their normal speed.

Considering a motor of the class indicated in Fig. 1, we find that the stator or transformer field, as we will call it, will induce in the rotor an E.M.F. along the axis C C. This E.M.F., to which we will refer as the working E.M.F. and designate by E T, being due to static

induction (transformer action), will lag by 90 degrees behind the inducing field, and will consequently be nearly in phase with the E.M.F. impressed on the stator. Its periodicity and magnitude are independent of the speed at which the rotor revolves, and only vary with the magnitude and periodicity of the transformer field. When the rotor is at rest, this E.M.F. sets up a heavy short-circuit current in the rotor along the axis C C. With increasing speed a counter E.M.F. is set up which prevents a short-circuit, so that under these conditions, and in the direction of the C C axis, the motor may be looked upon as a transformer with a considerable amount of leakage, whose secondary works on a circuit having only a small amount of self-induction. The rotor current in the axis C C, to which we will refer as the armature current, lags behind the secondary E.M.F., and the stator or primary current will lag behind the impressed E.M.F.; the phase difference, however, will not be greater than that existing in a badly designed transformer, and owing to the same reasons in both cases it will decrease with increasing load.

The rotor winding is, however, the seat of a further E.M.F. induced therein by the rotation of the rotor conductors in the primary field of the motor. This E.M.F., which we will designate by E R, is set up along the axis D D, and its magnitude depends on the magnitude of the transformer field and the speed of rotation; its periodicity is equal to that of the transformer field. Since the rotor is short-circuited along D D, E R will set up a current in the rotor windings. Owing to the great self-induction of the motor along the D D axis, this current will lag by nearly 90 degrees behind its E.M.F. As this E.M.F. must be in phase with the transformer field, the magnetising component of the current along D D, and the field it produces in that direction, will be nearly in quadrature with the transformer field. We have already seen that the armature current is nearly in quadrature with the transformer field; it must accordingly be nearly in phase with the secondary field produced by rotation, and which, in space, is at right angles to C C. It is to this last field, which we will call the motor field, and to the armature current that the torque of the motor is due.

As the position of the axes along which the armature current and the motor field act is the most advantageous it is possible to secure, there is no room for improvement in this direction, but the torque can be increased by bringing the armature current and the motor field more nearly into phase. Also the phase difference between the stator E.M.F. and current can be varied to any extent and in any direction by varying the phase relation between the armature current and the E.M.F. due to static induction along C C, or, in other words, between the armature current and the transformer field. If the armature current lags behind E T, then the stator current will lag behind the E.M.F. impressed on the stator; if, however, the armature current leads E T, then the stator current will lead the E.M.F. impressed on the stator, the conditions being equivalent to a capacity load on a transformer.

Before we proceed to indicate how, for the motor shown in Fig. 1,

the phase of the armature current can be adjusted with regard to the phase of the transformer field, it will be well to examine more exactly the conditions prevailing in the axis C C of the rotor. There is, first of all, E T, induced by a transformer field; then a back E.M.F., to which we will refer as E B, and which is set up in the axis C C by rotation of the rotor conductors in the motor field; it is of the same period as the latter, consequently also of the same period as the transformer field and E T; it depends for its magnitude on the magnitude of the motor field and the speed of rotation, and at a speed slightly above the synchronous it equals E T in magnitude; it is further in phase with the motor field, and consequently not quite in phase with E T. A third E.M.F. acting in this circuit is E S, the E.M.F. of self-induction, principally due to the very appreciable amount of leakage between secondary and primary in the transformer axis; this E.M.F. is proportional to the rotor current, and lags 90 degrees behind the same. The resultant of these three E.M.F.s in phase magnitude and direction is a small E.M.F., which goes to cover the ohmic losses in the rotor, and which we will call E W; it is co-phasal with the armature current.

The phase of E T is practically fixed by the phase of the E.M.F. impressed on the stator. The phase of E S is fixed by the phase of the armature current; its magnitude is determined by the quality of the design. The counter E.M.F. is dependent on the phase of the motor field, and it is by influencing the phase of the motor field that the author influences the phase of E B, and with its help adjusts the phase of the resultant E W and the phase of the armature current.

It is well to remember that even when the armature current has been brought into phase coincidence with E T the stator current will still lag to some extent behind its E.M.F. on account of the phase difference introduced into the primary circuit by the self-induction of the same. By forcing the armature current to lead E T even that phase difference may be eliminated, but one runs the risk of again bringing the armature current and the motor field appreciably out of phase, and thus increasing the armature current beyond that amount which would suffice in the case of complete phase coincidence. Thus, although the power factor can always be brought up to unity, and although the stator current can even be made to lead its E.M.F., it is not in all cases possible to achieve these results without impairing the efficiency of the machine. It is nevertheless always possible to obtain extremely high power factors without lowering the efficiency.

The method by which the author varies the phase of the motor field in these motors consists in introducing into the circuit D D an auxiliary E.M.F. differing in phase from E R. The resultant of the two is then responsible for the motor field, and the author has found that an auxiliary E.M.F. differing by about 90 degrees from E R, or materially in phase with the motor field, gives the best results. Under these conditions the greatest phase displacement of the resultant E.M.F. can be obtained with the smallest auxiliary E.M.F., and without materially influencing the motor field strength.

It would seem at first sight that it would be simpler to introduce

into the CC circuit an auxiliary E.M.F. which would influence the phase of the secondary current directly. The author has made quite a number of tests in this direction, and has found no difficulty in obtaining coincidence of phase between stator current and E.M.F. for light loads and for constant values of secondary current. Now this secondary current cannot be constant, but varies with the load ; consequently such a method has no great practical value. If it be adopted the E.M.F. should be derived from a non-inductive resistance, or a capacity on which an E.M.F. of suitable phase is impressed. By this means one can avoid the inclusion of additional self-induction in the rotor circuit in the C C axis, when very much better results will be secured.

It is absolutely necessary for the working of this motor that there should be as much self-induction as possible along the motor field axis ; but it is equally important that there should be as little self-induction as possible in the motor, along the transformer axis. The phase of the auxiliary E.M.F. inserted in the C circuit should coincide with the phase of the field along that axis. Of course this auxiliary E.M.F. can be obtained from any convenient source, provided the periodicity is the same as that of the E.M.F. impressed on the stator and its phase a suitable one. The proper phase of the auxiliary E.M.F. to be applied to the D or C circuit bears a simple relation to the phase of the E.M.F. (E) impressed on the stator. In the general case indicated in Fig. 9, let the brush system be so placed that one of the brush sets, C C for instance, forms an angle a with the stator field axis F ; then the phase of the auxiliary E.M.F. (E_1) to be included in the D circuit, must differ by α degrees from the phase of E, and the phase of E_2 must differ from it by $90 + \alpha$ degrees. For $\alpha = 0$ the phase of E_1 becomes equal to the phase of E, and the phase of E_2 is in quadrature with it.

It was always recognised that in order to make a commercial success of such a compensated motor it would be necessary to avoid accessory apparatus as far as possible, and for that reason the author arranges to procure the auxiliary E.M.F. from the motor itself. We have seen that the motor field is practically in quadrature with the transformer field. The motor field will therefore induce statically an E.M.F. in phase with the transformer field, and *vice versâ*. If the auxiliary E.M.F. is then to be obtained from the motor itself, it can be got from a winding whose axis forms an angle of $\frac{180}{n}$ degrees with the axis of the brushes to which it is to be connected ; it will then be acted upon by a field of the required phase.

Fig. 10 indicates the position of these windings for the general case illustrated in Fig. 9, and, as will be seen from the performance curves of actual motors, annexed to this paper, this method of obtaining the compensating E.M.F. gives excellent results in practice.

It remains for us finally to consider the question of sparking, and although for the purpose of this paper it was found convenient to deal with this last, it is in reality a question of first importance, and the difficulties met with in this respect gave some trouble and led to delay.

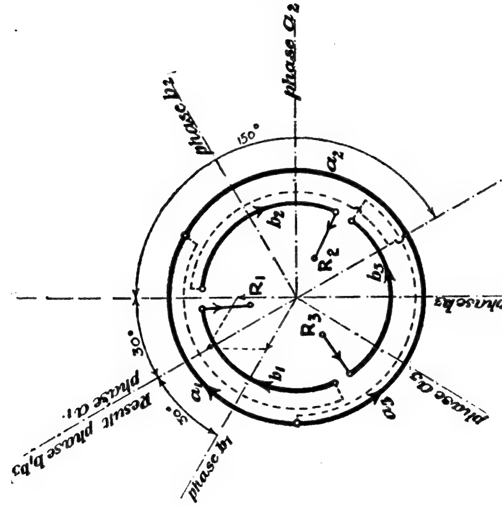


FIG. 11.

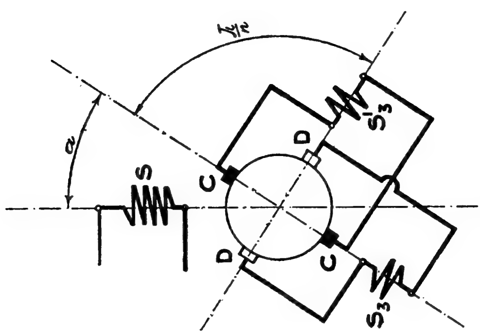


FIG. 10.

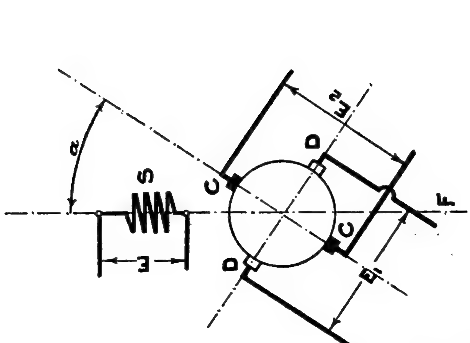


FIG. 9.

It has been shown that the motor in Fig. 1 is electrically the equivalent of a motor with a squirrel cage; it must, therefore, also behave like a motor having a rotor provided with a polyphase winding short-circuited by means of slip-rings or otherwise; nothing in the nature of the motor would, therefore, be changed if, in addition to the two sets of brushes on the commutator, say, three equidistant points of the rotor were short-circuited when up to speed.

This scheme was resorted to with the object of relieving the commutator of the greater part of the current it was carrying, and thus diminishing sparking. The sparking was, indeed, entirely suppressed. The same arrangement was used at starting, when resistances between the three equidistant points were inserted by means of slip-rings, and gradually cut out as the speed was increased. It was, however, found that the ordinary rotor windings in use did not answer the purpose at all well, particularly when phase compensation was attempted. It is easy to see that with a number of points of the rotor winding directly short-circuited, for instance over slip-rings, any E.M.F. impressed on the rotor by means of the one or the other brush set would send a heavy and useless current through these slip-rings; phase compensation is practically impossible under such circumstances. Then, again, it is advantageous to have a very low voltage on the commutator, whilst a high voltage on the slip-rings is important.

An obvious way out of the difficulty is to use two distinct windings on the rotor, the one connected to the commutator, and the other to the slip-rings. This arrangement lowers the output of the motor very appreciably, because it makes it impossible for that part of the winding which is connected with the commutator to be made use of in normal running (when the machine operates as a shunt induction motor), as almost the whole of the current induced in the rotor will flow through the slip-rings.

To get over the difficulty completely, the author makes use of a continuous-current and polyphase winding in his rotors, combined in such a way that, as far as the commutator is concerned, only the continuous-current winding is operative; whilst both continuous and polyphase windings are operative as far as the slip-rings are concerned. The best possible use is thus made of the rotor winding space and copper. The commutator voltage depends on the continuous-current winding only. The polyphase winding is so disposed with regard to the continuous-current winding as to obtain at the slip-rings the highest possible voltage resulting from the combination of the two windings.

For the case of a 3-phase winding (and this will mostly be used), the relative positions and the mode of connection of the two windings is shown in Fig. 11. Since any continuous-current winding can be considered as a mesh-connected 3-phase winding, this arrangement can be looked upon as the combination of a 3-phase mesh and star winding. The three legs of the mesh are designated by a_1, a_2, a_3, whereas b_1, b_2, b_3 stand for the three star legs, and R_1, R_2, R_3 for the three slip-rings. The dotted lines show how the two must be interconnected, the arrows indicate the momentary direction of the induced E.M.F.s,

assuming a clockwise direction of rotation and a direction of the magnetic field from top to bottom of the sheet of paper. If a is the voltage per phase of the mesh, and b that of the star winding, then the maximum obtainable voltage between any two slip-rings will be $=a+b\sqrt{3}$. This winding makes it impossible for the brush sets

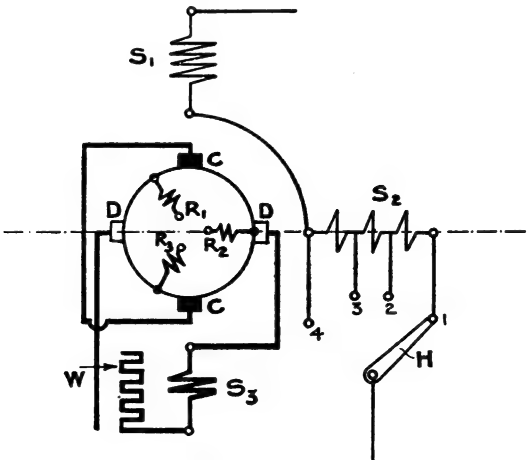


FIG.12.

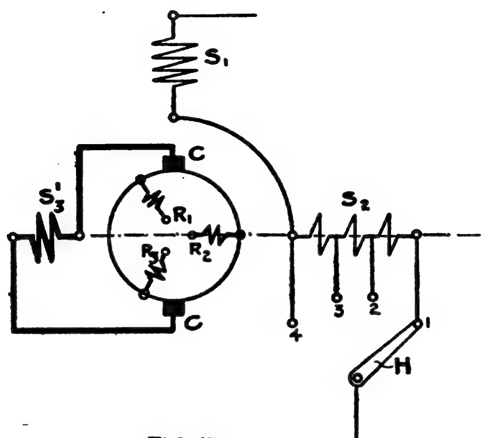


FIG.13.

disposed on the commutator to be at any time short-circuited, or even nearly so, over the slip-rings; a great number of turns will always be interposed. Tests have shown that a motor provided with such a rotor can be fully compensated without raising by more than two or three per cent. the current taking its way over the slip-rings.

The complete motor is shown diagrammatically in Figs. 12 and 13 in

its two early forms, as arranged for "constant speed work." For the sake of clearness, the slip-rings have been omitted from the figures; they are connected to the points R_1, R_2, R_3 of the rotor winding.

The arrangement shown in Fig. 12 allows of the conversion of the motor from a series induction to a shunt induction machine by the gradual closing of the D circuit in combination with a gradual reduction of the number of turns in the group S_2, and, when desired, also in combination with a gradual decrease of the resistances inserted between the slip-rings. A reduction of the resistances inserted in the D circuit and a reduction of the resistances between the slip-rings increases the shunt excitation; a reduction of the number of turns in the group S_2 after the motor has started reduces the series excitation. At first both methods were used simultaneously on account of sparking difficulties, and one was naturally led to simplify this disposition by leaving out the D circuit altogether. The motor shown in Fig. 13 was thus evolved, and quite a number of such machines were executed.

The author thinks that although this last form of motor is simpler than that shown in Fig. 12, electrically it is somewhat inferior. It may perhaps not be at once clear how and why the motors shown in Figs. 12 and 13 can be compensated with the help of the same auxiliary E.M.F.s as were used for that purpose in conjunction with the motor as shown in Fig. 1. Considering Fig. 12, and remembering that the smaller the rotor resistance the faster will a shunt induction motor run, it must be evident that the speed in this particular case will be determined by the slip-ring circuit, if short-circuited, for the latter will undoubtedly have a smaller relative resistance than the circuit of the continuous-current winding closed over the armature and field brushes (C C and D D). There will be two alternative paths for the armature current, the one over the slip-rings, the other over the brushes C C; the former will carry all the current, not only directly on account of its smaller relative resistance, but also because this smaller resistance determines a higher motor speed, thus increasing E B in the latter circuit, whilst E T remains constant. There will also be two alternative paths for the field current, the one over the slip-rings, the other over the brushes D D. The greater part of the motor field will be supplied by the current through the former, and the smaller part by the current through the latter; the auxiliary E.M.F. (E_1) will only act on the latter circuit, but in exactly the same manner as before when the rotor was only short-circuited by means of brushes disposed on the commutator.

When including the auxiliary E.M.F. (E_2) in the armature-circuit of the continuous-current winding by means of the brushes C C, whilst the slip-rings are short-circuited, as shown in Fig. 13, a current is caused to flow in that circuit mainly through the agency of E_2. As before, E W will determine the phase and magnitude of this current; this E.M.F. is again the resultant of E T, E B (which is greater than it would be if the slip-rings were not short-circuited, and nearly equals E T) and E S. Under these circumstances the current flowing in this circuit will be practically constant for all loads (until the speed begins

to drop materially), independently of the current flowing over the slip-rings, and will cause a decrease of the latter. In phase, the current flowing by way of the commutator will lead E T, whereas the current flowing by way of the slip-rings will lag behind E T. The resultant rotor ampere turns in the armature axis can therefore be made to coincide with or to lead E T. The resultant stator ampere turns must balance the resultant rotor ampere turns, and the stator current can therefore be made to coincide with or even lead the E.M.F. impressed on the stator. It is seen that in this case external self-induction is only included in part of the rotor winding in the armature axis and in that part through which the current remains practically constant, so that its detrimental effects are greatly minimised. The beneficial effect of this arrangement as far as the power factor is concerned is greatest at no-load, and diminishes as that component of the rotor ampere turns in the armature axis which is due to the current flowing by way of the slip-rings increases; the result is a very constant and high power factor.

The conversion from series induction to shunt induction working cannot be effected as smoothly with the help of the slip-rings only (Fig. 13) as it can with the help of the D circuit (Fig. 12); and in the former case it is quite impossible in practice to avoid a very marked falling off in the starting torque curve, which makes this form of motor unsuitable when heavy and sustained starting torques are required. For light work, however, it is very useful, and its power factor under normal working conditions approaches unity. On the other hand, the starting torque curve of the motor in Fig. 12 (with or without the help of slip-rings) is an almost straight line, and the motor in this form can be used in all those cases in which heavy and sustained starting torques are required—for instance, for lift and similar work.

The slip-rings are a very unwelcome complication, at any rate for smaller machines, but a way was found of doing without them by simply suitably dimensioning the rotor winding. The experience gained during the numerous tests which were carried out on such machines at one time or another led to the fuller recognition of the factors influencing the process of commutation, and showed the way to the correct design of such armatures.

In the continuous-current machine we obtain sparkless commutation whenever it is possible, to balance the reactance voltage by a voltage induced in the short-circuited coil by some external means, or simply by the voltage resulting from the unequal distribution of the current under the brush. This last process is automatic, but limited in its effect; it fails when the balancing voltage can only be obtained by raising the current density in some part of the brush beyond the permissible limit. For the continuous-current machine the problem is therefore a comparatively simple one; whereas it is far more complicated for the machines under consideration. In the continuous-current machine there is only the reactance voltage to provide for: this may vary in magnitude, but its phase is constant; in the motor

under consideration we have to deal with three distinct E.M.F.s of different phase and varying magnitude. As in the continuous-current machine, there is a reactance E.M.F. to consider, which varies in magnitude with the speed and the rotor current, and is nearly in phase with the latter: in addition there is an E.M.F. due to the static induction of the motor field (axis D) on the coil undergoing commutation, whose magnitude, of course, depends on the strength of the motor field, while in phase it lags about 90 degrees behind the reactance E.M.F. The third E.M.F. is that due to the rotation of the short-circuited coil in the transformer field (axis C), whose magnitude depends on that field strength and on the speed, while in phase it is opposite to the E.M.F. due to static induction. The resultant of these three is the one to be balanced, and this varies in phase as well as in magnitude. This fact makes it particularly difficult to balance it by inducing in the commutated coil a suitable E.M.F. by some external means, since that E.M.F., in order to be effective, would have to follow the variations of the resultant not only in magnitude, but also in phase. At any rate, for small machines one must fall back on commutation by means of unequal distribution of current under the brush, which at once presents limits to the designer.

At starting, only the first two E.M.F.s above mentioned need be considered, and as a rule the second will be the greatest. As the motor speeds up the third comes into play; being of opposite phase to the second, its effect is to diminish the latter. When synchronism is reached, these two practically cancel out, and there only remains the first, or the reactance E.M.F., to balance.

Taking advantage of these conditions, and with careful design of the rotor, it has been possible so far to dispense with the slip-rings altogether up to sizes corresponding to about 50 H.P. at some 400 revolutions; such smaller machines are made on the lines of Fig. 12, but with only one winding on the rotor and without slip-rings. In motors of greater power intended for continuous running at full load, provision is made for short-circuiting a number of points on the rotor winding, so as to relieve the commutator and to be able to make a smaller one do.

The complete diagram of connections of a motor for intermittent load and designed to run in both directions (for instance, for elevator service), is given in Figs. 14, 15, 16, and 17; in this case it will be noticed that the resistances in the field circuit are suppressed. In order to reverse the direction of rotation, it is preferable to reverse the current through the winding S_1. Rotation would also be reversed if the current through S_2 were reversed; but as the tappings must be unequally spaced in the latter, such a course would lead to complications in order to restore the proper stepping.

The average results which can be obtained with such motors vary somewhat with the periodicity of the supply and the number of poles of the motor. Taking as a basis 50 periods, and what can be considered as a normal number of poles, and further assuming that the voltage at the terminals is not raised at starting above the value for

which the motor is designed, a maximum torque, two to two and a half times the normal, can be secured with about one and a half times the

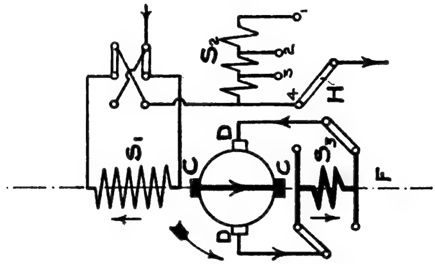


FIG. 17.

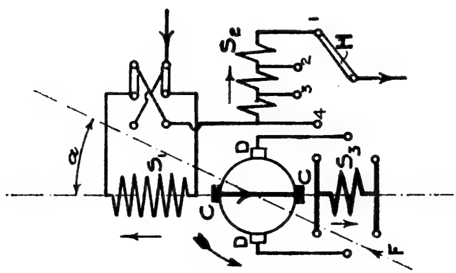


FIG. 16.

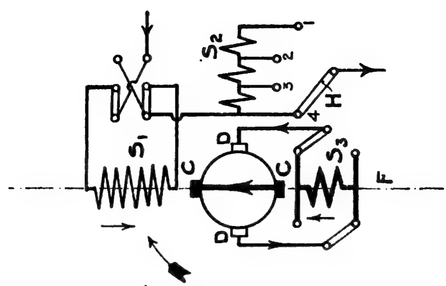


FIG. 15.

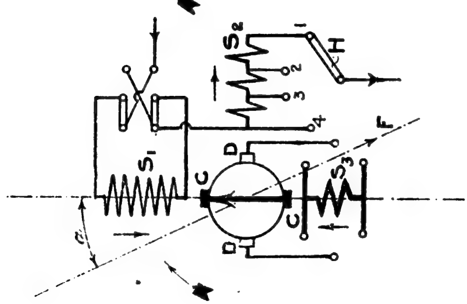


FIG. 14.

normal current. The motors will start light with about no-load current, or not more than one-fourth of the normal current.

The power factor can always be brought up to unity; this, however,

may entail a heavier current in the rotor and slightly higher losses. On that account the smaller motors are not, as a rule, fully compensated, as it does not appear advisable to lower the efficiency for the sake of improving the power factor by some 5 per cent. Thus for small machines up to 6 or 7 H.P. the power factor is only raised to 0·7 or 0·8 at no-load, reaching 0·9 to 0·94 under load. The power factor curve rises very rapidly at first, and as the load increases it remains nearly constant.

The larger machines are designed for a power factor seldom falling below 0·9 and reaching 1; these can be made to take a leading current when desired.

The efficiency of these compensated motors closely approximates to that of good asynchronous machines with squirrel-cage rotors. In the smaller sizes it falls some 2 to 3 per cent. below the latter, as is to be expected; since for small outputs only a small increase in the losses is sufficient to reduce the efficiency by several per cent. In this case the increased losses are mainly due to the friction of the brushes on the commutator and to the C^2R losses in commutator and brush-gear. In the larger sizes the efficiency quite equals, and sometimes, for a large number of poles and high frequencies, materially exceeds, that of the corresponding asynchronous motor.

Altering an ordinary asynchronous single-phase motor to the construction which we have described will increase its output from 30 to 40 per cent., besides vastly improving its power factor; but the increased output and the better power factor of these machines do not entirely compensate for the increased losses.

The number of poles which are here considered as normal run somewhat as follows: Four up to about 3 H.P.; 4 and 6 up to about 10 H.P.; 4, 6, and 8 up to about 40 H.P., and so on. An increase in the number of poles for the same frame decreases the maximum starting torque obtainable, roughly, in the same proportion as the increase in leakage, while the current for a given torque increases.

The power factor can be maintained at its high values for any number of poles likely to be adopted. But the efficiency naturally falls off with an increasing number of poles, since the speed and output are reduced, whilst the losses remain much the same.

The maximum starting torque varies inversely as the square root of the periodicities, the current taken increasing nearly in the same proportion. The power factor can be maintained at its high values for any periodicity; the efficiency, however, falls off a little with an increase in the number of cycles.

The maximum output varies with the square of the terminal voltage, and the starting torque also increases in the same proportion as long as saturation is not reached. By boosting up the terminal voltage at starting, a torque equal to four times the normal can be obtained with about three times the normal current.

The behaviour of these compensated machines under normal running conditions is interesting, and differs in many respects from that of the ordinary asynchronous induction motor.

Thus, for instance, at no-load the speed is, as a rule, a little above the synchronous—some 2 to 4 per cent., the actual amount depending on the auxiliary voltage impressed on the field brushes. At full load the drop in speed reaches about 10 per cent. in the smaller sizes, and where there is no means of short-circuiting, a number of points of the rotor winding, independently of the commutator, are provided. In the larger sizes, and where independent short-circuiting devices are employed, the slip approximates more nearly to that of the ordinary asynchronous motor. When heavily overloaded, the speed may drop to about two-thirds of the synchronous before the motor will pull up. This great drop acts as a safety-valve to some extent, and prevents the motor from falling out of step under momentary heavy overloads.

The starting gear for the smaller machines simply consists of a 3-pole, 2-throw switch. As a rule S_2, the stator series field winding, is provided with two tappings besides the beginning and end: these are taken to four terminals; the end is joined directly to the beginning or end of the S_1 winding, according to the direction of rotation required. In the starting position the switch is connected to one of the three free terminals of the series field winding S_2, the choice depending on the torque required. In the working position the S_2 winding is entirely cut out, and the shunt circuit closed on the S_3 winding. It is, of course, best to throw the switch over into the working position at the time when the motor has reached its normal speed, but no damage or undue rush of current will result if the exact moment has not been correctly estimated. If the motor starts light, the switch can be thrown over as soon as the motor has made a few revolutions; if left in this starting position the speed will rise to perhaps 20 or 30 per cent. above the synchronous, but will at once fall to the normal on the switch being brought into the working position—there will be a momentary rise in the current not exceeding 25 per cent. If the motor starts under load the switch can be thrown over at any time after the motor has reached, say, a third of its normal speed. This margin is certainly sufficient, even when the motor is operated by unskilled men. If the motor does not start at all in the first position, it is useless to throw the switch over, as this will only cause a short-circuit.

Larger motors are provided with controllers connected according to Figs. 14 to 17. The current is switched on gradually, and the motor starts according to the torque required on the first, second, or third point. With such a controller it is possible to regulate the speed of the motor to a great extent. If the S_3 winding is only in circuit on the last point, then on all the others the motor will have a series characteristic. If this winding is kept in circuit, then the speed, even at no-load, can be greatly reduced by moving the controller back; that reduced speed will, however, not be maintained nearly constant under load, but will fall off much in the same way as the speed of a shunt motor with weakened field. This drop will be the greater the more of the S_2 winding is switched into circuit. Under these conditions the power-factor and efficiency fall off to about two-thirds of their normal value.

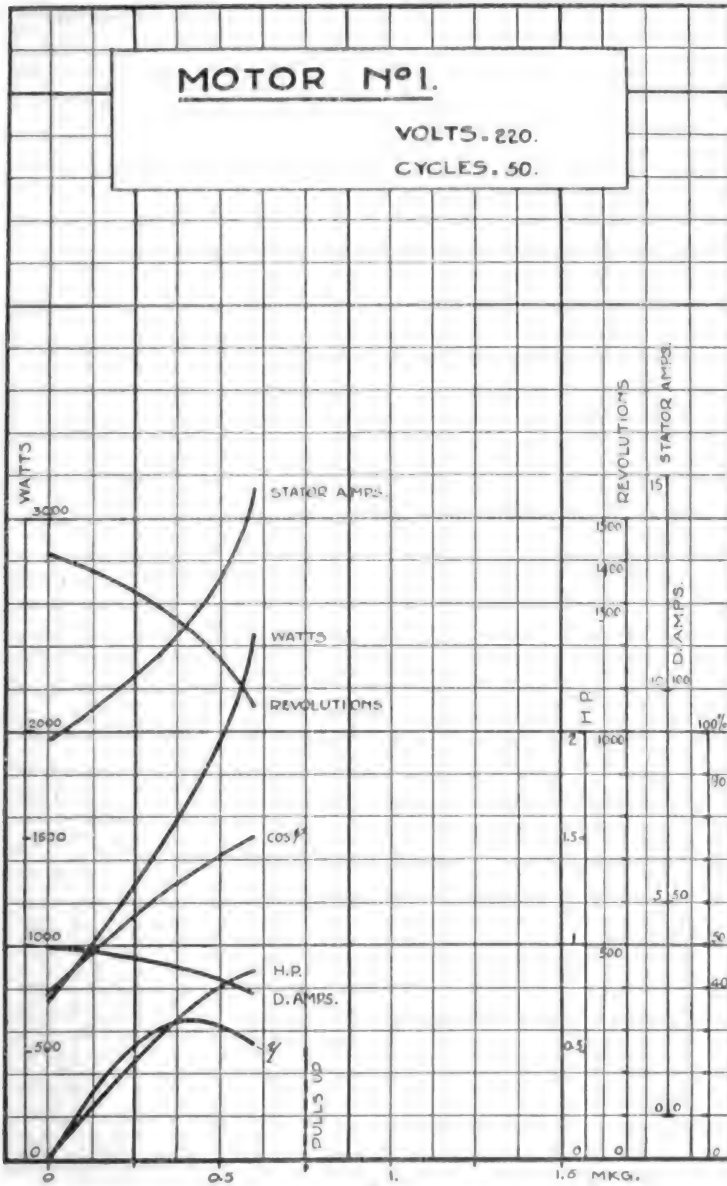

MOTOR Nº1.
VOLTS. 220.
CYCLES. 50.
WATTS
3000
2000
1500
1000
500
0
STATOR AMPS.
WATTS
REVOLUTIONS
COS φ
H.P.
D. AMPS.
η
PULLS UP
REVOLUTIONS
1500
1400
1300
1000
500
0
STATOR AMPS.
15
10
5
0
D. AMPS.
100
50
0
H.P.
2
1.5
1
0.5
0
100%
90
50
40
0
0
0.5
1.
1.5 MKG.

FIG. 18.

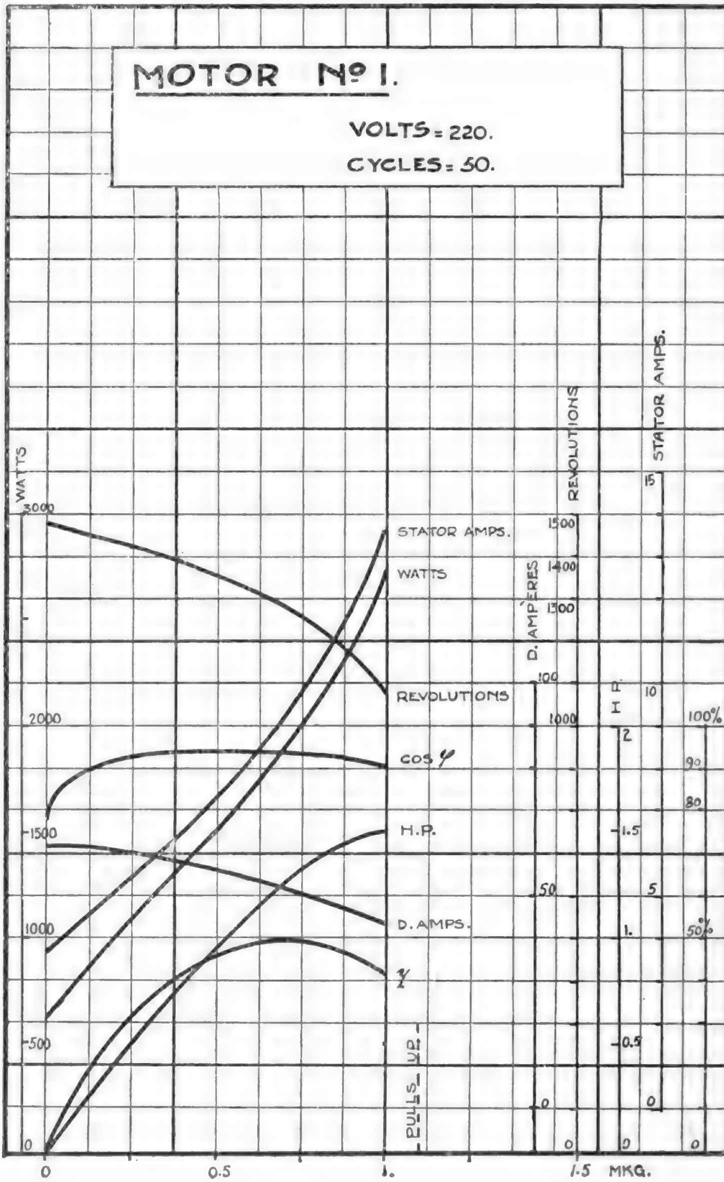

MOTOR No. 1.
VOLTS = 220.
CYCLES = 50.
WATTS
3000
2000
1500
1000
500
0
STATOR AMPS.
WATTS
REVOLUTIONS
cos φ
H.P.
D. AMPS.
η
PULLS UP
D. AMPÈRES
100
50
0
REVOLUTIONS
1500
1400
1300
1000
0
H.P.
2
1.5
1.
0.5
0
STATOR AMPS.
15
10
5
0
100%
90
80
50%
0
0
0.5
1.
1.5
MKG.

FIG. 19.

Better results with regard to efficiency and power factor during starting can be obtained in special cases by regulating the E.M.F. impressed on the D circuit, increasing it as the speed decreases, but this necessitates a little more complication in the connections and windings.

In order to illustrate more fully the properties of these motors, a number of curves are appended which have been obtained by actual tests on some of the smaller motors built. These machines have not been chosen as exemplifying the best results which can be secured, but were selected because comparative tests are available, and these, it is thought, will present the greater interest.

The motor No. 1 was built into the frame of a standard 50-cycles 4-pole machine, which, as an asynchronous squirrel-cage single-phase motor, gives ¾ B.H.P. continuously, at some 1,460 revolutions. It was fitted with an experimental continuous-current armature, and tested both as a plain shunt induction motor, with a rotor short-circuited along two axes stationary in space and displaced by $\frac{180}{n}$ degrees (see Fig. 1), and as such an induction motor, with the addition of the improvements described in this paper. (See Fig. 15 or 17.)

The armature was not of the most suitable design, but as the same one was used in both cases, the comparison is fair, and clearly shows the enormous advantage of the compensation. The curves relating to the first test are shown in Fig. 18; those relating to the second, in Fig. 19. It can be seen that the addition of the author's compensating winding caused the no-load current to fall from 9·8 to 3·7 amperes, and the power factor to rise from 0·38 to 0·78, while the maximum efficiency rose from 32·8 per cent. to 49·5 per cent. Whereas without compensation the output at maximum efficiency was 0·7 B.H.P., with compensation it reached 1·25 B.H.P. In the first case the speed dropped to 1,235; in the second, and notwithstanding the greater output, to only 1,285; the respective power factors being 0·665 and 0·935. With a more satisfactory armature both motors would be improved; their relative performances, however, would remain the same. With such an armature the compensated motor gives a continuous output of 1·25 B.H.P., and shows a smaller drop in speed. The efficiency in this case is about 3 per cent. less than that of the corresponding squirrel-cage motor.

In most of the curve sheets included in this paper it has been found conducive to greater clearness sometimes to place the zero of some of the vertical scales on different levels; attention is drawn to this in order to avoid possible misunderstandings.

A comparison between an asynchronous induction motor with squirrel cage, and a motor of this new type, is afforded by Figs. 20 and 21. The same frame, No. 2, has been used in both cases; it is that of a standard single-phase motor giving continuously 1·5 B.H.P. at 50 cycles and about 1,460 revolutions when wound for 4 poles. This machine had never been built with 6 poles, on account of the bad performance expected at the lower speed.

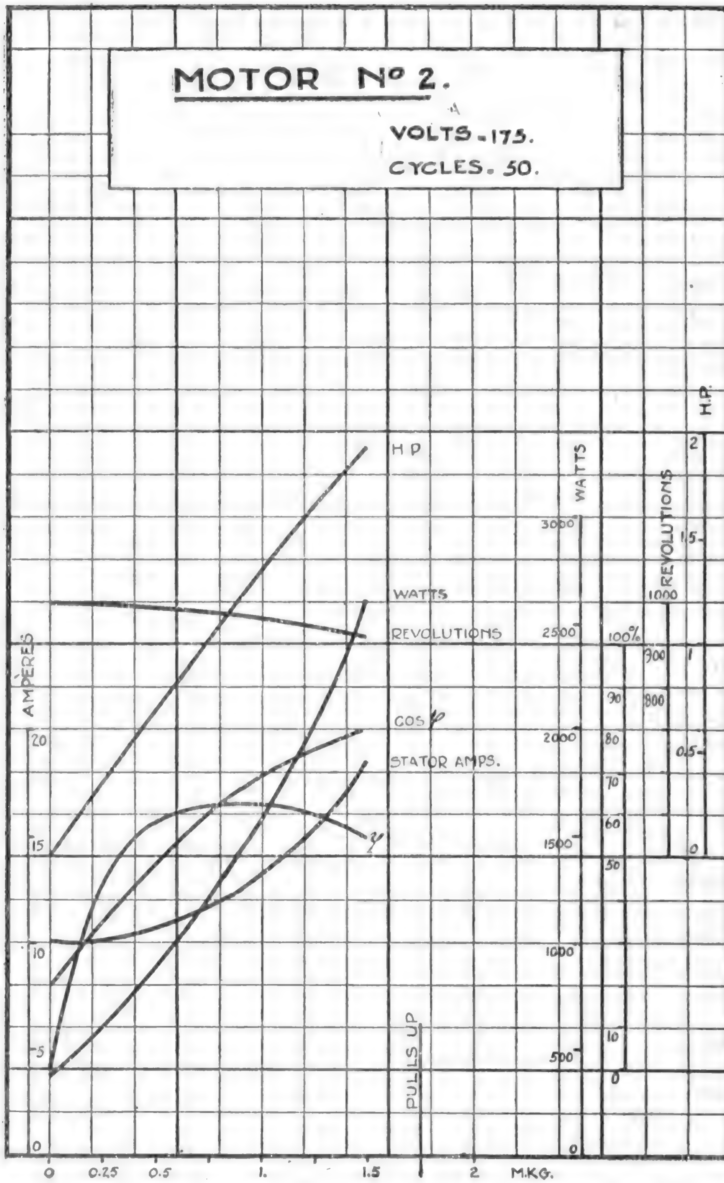
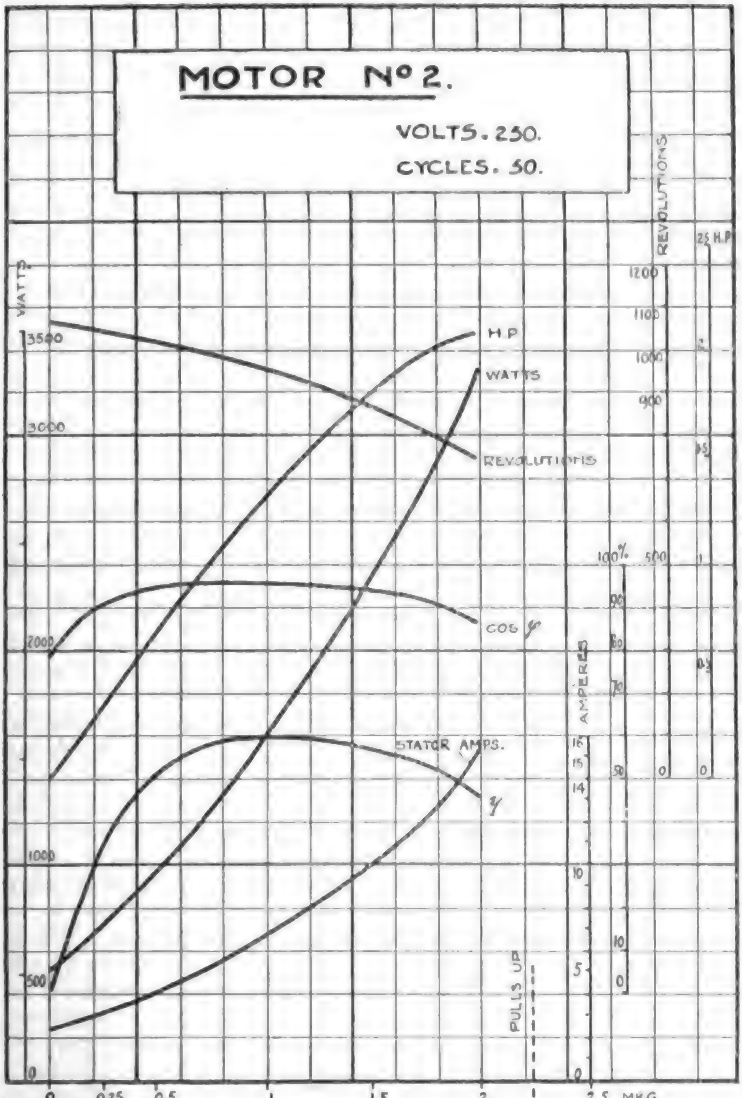

MOTOR No 2.
VOLTS = 175.
CYCLES = 50.
H P
WATTS
REVOLUTIONS
COS φ
STATOR AMPS.
η
AMPÈRES
WATTS
REVOLUTIONS
H.P.
PULLS UP
0
5
10
15
20
500
1000
1500
2000
2500
3000
0
10
50
60
70
80
90
100%
800
900
1000
0
0.5
1
1.5
2
0
0.25
0.5
1.
1.5
2
M.KG.

FIG. 20.



MOTOR Nº 2.
VOLTS. 250.
CYCLES. 50.
WATTS
3500
3000
2000
1000
500
0
REVOLUTIONS
1200
1100
1000
900
500
0
H.P
WATTS
REVOLUTIONS
COS φ
STATOR AMPS.
η
AMPERES
16
15
14
10
5
0
100%
90
80
70
50
10
0
PULLS UP
0
0.25
0.5
1
1.5
2
2.5 MKG.

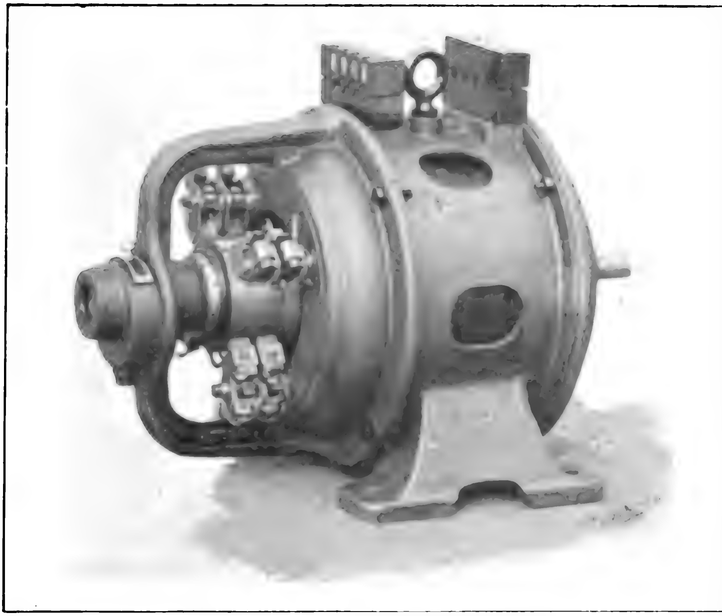
FIG. 21.

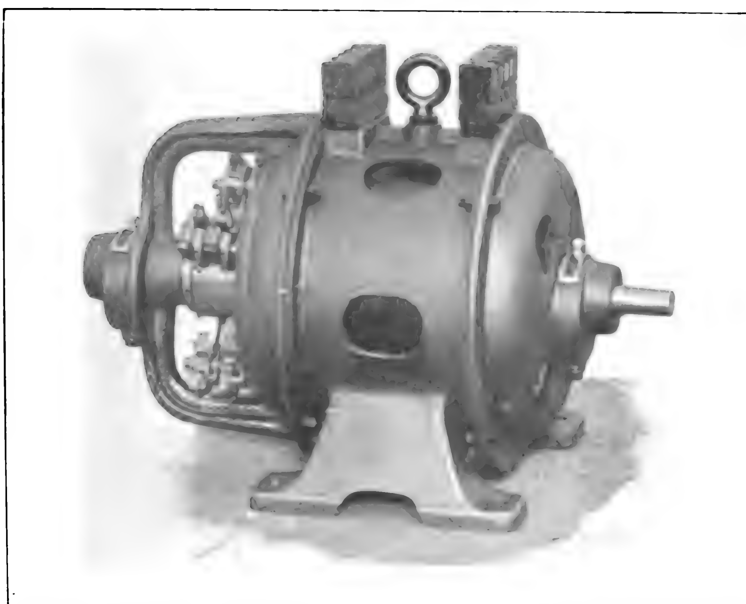
As an experiment it was wound for 6 poles, and the result of the tests is shown by the curves in Fig. 20. The machine in this form is of no practical value, as can be gathered from these curves, and it gets too hot. The densities would have to be much reduced to keep within the limits of temperature rise, and to reduce the no-load current as far as possible. With 6 poles an output of about 0·95 B.H.P. could be obtained, with a no-load current of not less than 70 per cent. of the full-load value.

Preliminary tests showed that sufficiently good results would be obtained with the addition of the author's improvements. This stator was re-wound for 250 volts (to suit a certain supply circuit), the densities being kept practically the same: speaking exactly, they were lowered by 4 per cent. The result was a good commercial machine, and is illustrated by the curves in Fig. 21. In this form 1·3 B.H.P can be obtained continuously from that frame when wound for 6 poles. Comparing the two sheets of curves, and reducing the stator current of the first to 250 volts, we find that at no-load the speed has risen from 950 to 1,060, the power factor from 0·2 to 0·78, whereas the current has fallen from 7 to 2·5 amperes. At full-load the speed is now 950 instead of 960, the power factor 0·952 instead of 0·68, the current 6·8 instead of 9 amperes, the efficiency 59·5 per cent. instead of 62·5 per cent., whereas the maximum torque which the motor can exert before pulling up has risen from 1·75 to 2·25 mkg. The maximum output, which of course takes the speed into consideration, has only increased by some 8 per cent. This improved motor, which is one of a standard series, easily starts with a pull of 2·5 mkg., that is 2·5 times the normal, while there is no sparking at the commutator either at starting or under normal running conditions. The general appearance of this machine is shown in Figs. 22 and 23.

Motor No. 3 shows another case where an ordinary squirrel-cage single-phase motor absolutely fails, whereas the new compensated motor gives excellent results. Frame and winding are identical in both cases. The results with the squirrel cage are shown in Fig. 24, those with the new motor connected as in Figs. 15 or 17 are illustrated in Fig. 25. The frame used is that of a standard single-phase 4-pole motor generally wound for 4 poles 50 cycles, and giving under these conditions 6 B.H.P. continuously. This frame was now wound for 8 poles and 85 cycles; the test with the squirrel cage showed that the machine was practically useless, whereas the results obtained with the new arrangement are quite good. This particular machine was designed for intermittent load. A comparison of the main data shows the following results at no-load: the speed of the squirrel cage was 1,270 as against 1,355, the no-load current 41 as against 12·8 amperes, the power factor 0·19 as against unity. The maximum B.H.P available was 5·5 and 8 respectively, so that the squirrel cage could not be worked normally at the required normal load of 5 H.P. The maximum efficiency is better by 2 per cent. for the compensated motor, reaching 66 per cent. at full-load.

The curves, Fig. 25, also show the variation in the rotor currents in





FIGS. 22 AND 23.

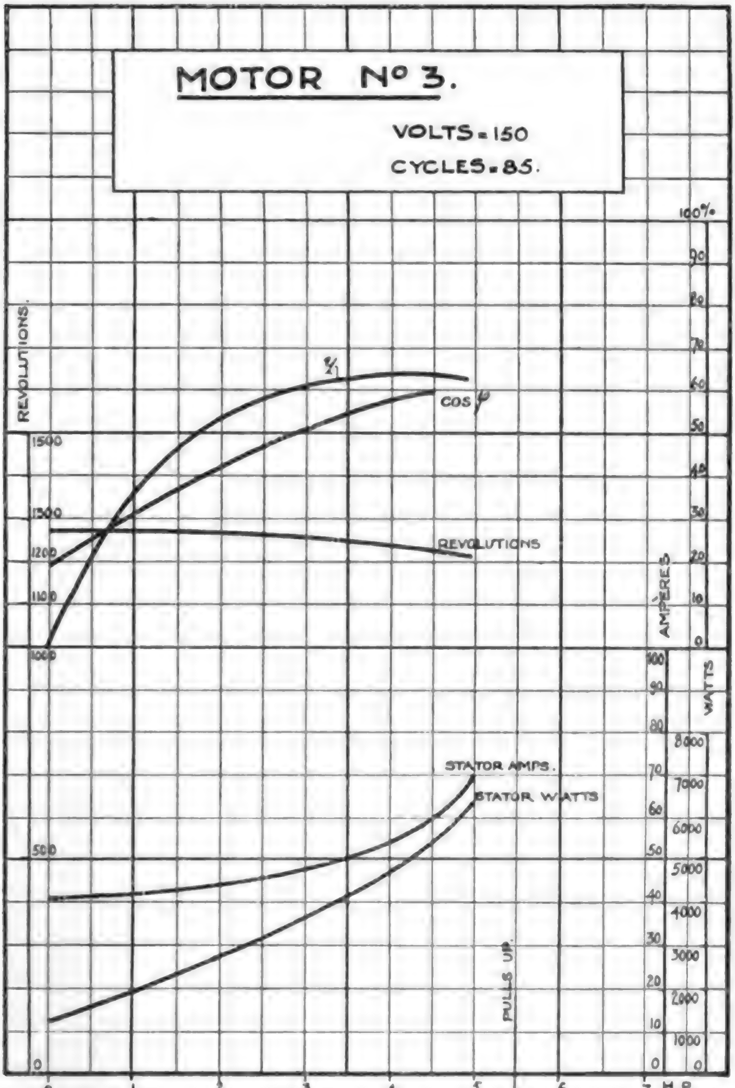

MOTOR N° 3.
VOLTS = 150
CYCLES = 85.
REVOLUTIONS.
AMPÈRES.
WATTS
PULLS UP.
η/1
COS φ
REVOLUTIONS
STATOR AMPS.
STATOR WATTS
100%
90
80
70
60
50
40
30
20
10
0
1500
1300
1200
1100
1000
500
0
100
90
80
70
60
50
40
30
20
10
0
8000
7000
6000
5000
4000
3000
2000
1000
0
0
1
2
3
4
5
6
7
H.P.

FIG. 24.

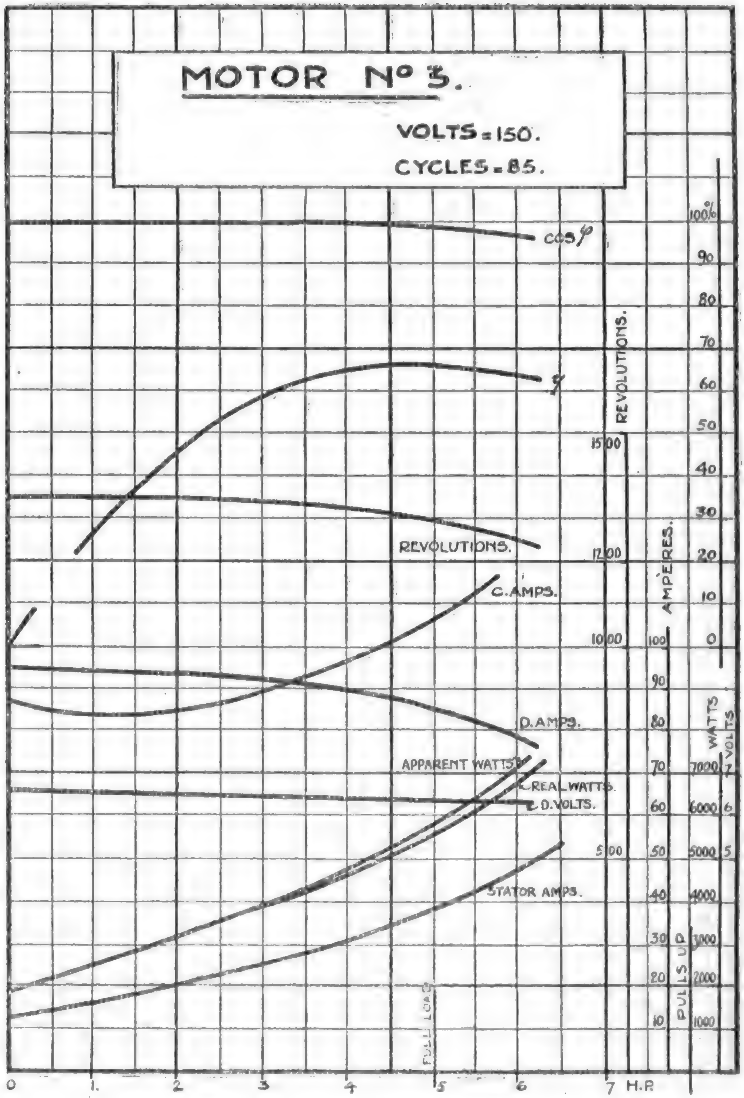

MOTOR Nº 3.
VOLTS = 150.
CYCLES = 85.
COS φ
η
REVOLUTIONS.
C. AMPS.
D. AMPS.
APPARENT WATTS.
REAL WATTS.
D. VOLTS.
STATOR AMPS.
FULL LOAD
REVOLUTIONS.
AMPÈRES.
WATTS
VOLTS
PULLS UP
100%
90
80
70
60
50
40
30
20
10
0
1500
1200
1000
500
100
90
80
70
60
50
40
30
20
10
7000
6000
5000
4000
3000
2000
1000
7
6
5
0
1.
2
3
4
5
6
7 H.P.

FIG. 25.

the C and D axes, as well as the value of the auxiliary E.M.F. (D volts) impressed on the D circuit. It has already been said that the overload capacity of these motors depended greatly on the value of this E.M.F.: in this case the experiment was tried. With 10·38 auxiliary volts on the D brushes the power factor was unity, the speed 1,266 revolutions, the output 7·97 B.H.P. at 63·1 per cent. efficiency, and the overload capacity 9 B.H.P. The current in the D axis rose to 110·5, that in the C axis to 174·5 amperes. It is owing to this large current in the latter axis that the efficiency was a little lowered. At lighter loads the current taken by the motor was leading. These last results have been added with the object of showing that care must be exercised in the predetermination of the auxiliary E.M.F.: if this be chosen too high the efficiency might suffer for the reasons already set forth. Particular care is required when high densities are adopted. The current in the field axis follows the same laws as an ordinary magnetising current.

We have so far been comparing the performance of the squirrel-cage motor with the new motor without auxiliary short-circuits in the armature, and have found that, at least for the smaller sizes and the lower periodicities, the latter is at a slight disadvantage with regard to efficiency; but even this disadvantage nearly disappears if, after the machine has been converted into a shunt induction motor by short-circuiting the rotor along two stationary axes, several points of the rotor are also short-circuited according to the diagram in Fig. 12. This increases the efficiency of the motor by several per cent. But even then the comparison is not really a fair one, since the starting properties have not at all been considered. There is no known method of starting an ordinary asynchronous single-phase motor which will bear the least comparison with the one here described; the most effective all make use of rotors provided with slip-rings; and it would be more correct to compare with this new type that form of the ordinary induction motor which allows of the best starting torque being obtained. If this be done the ordinary induction motor entirely loses its one remaining advantage, since the use of the slip-rings at once lowers its efficiency.

In Fig. 26 is shown a set of curves illustrating the starting performance of motor No. 3. The point of the starting switch to which this set of curves corresponds is one for which the proportion of ampere turns in the S_2 and S_1 windings is as 1 to 3·5. Similar sets of curves would be obtained for other points of the starting switch.

The full-line curves illustrate in detail the performance of the motor with varying load as a series induction motor (D circuit open). The speed for any given torque could be increased or decreased by moving the switch forward or backward. The dotted curves were obtained by gradually closing the shunt exciting circuit, beginning with a resistance of half an ohm in circuit when a speed of 860 revolutions (two-thirds of normal) had been reached, reducing this to ·15 ohms and then cutting it out altogether. It is seen that the available torque never sinks under 2·78 mkg., which corresponds to the full load, and that the speed curve is regular enough for all purposes. The

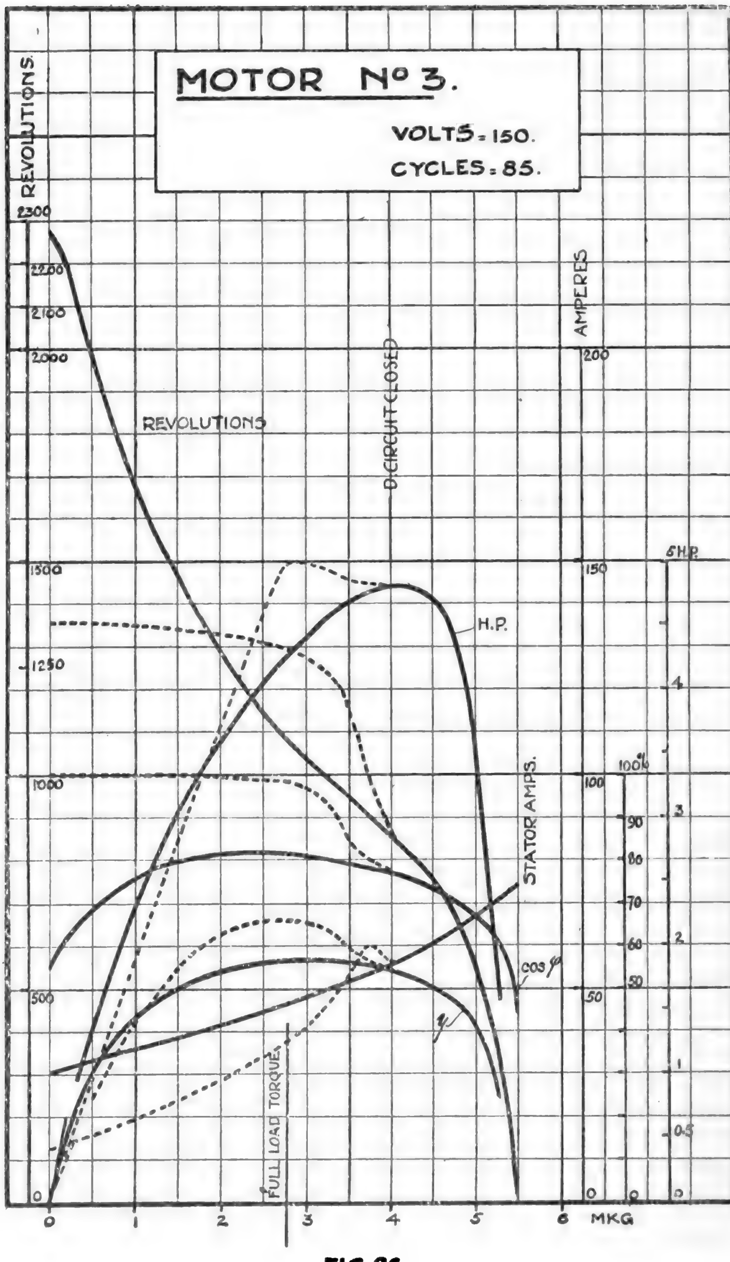

MOTOR No 3.
VOLTS = 150.
CYCLES = 85.
REVOLUTIONS
2300
2200
2100
2000
1500
1250
1000
500
0
REVOLUTIONS
D. CIRCUIT CLOSED
AMPERES
200
150
100
50
0
5 H.P.
4
3
2
1
0.5
0
100%
90
80
70
60
50
0
H.P.
STATOR AMPS.
cos φ
η
FULL LOAD TORQUE
0
1
2
3
4
5
6
MKG

FIG 26.

maximum torque obtainable, however, only just reaches twice the normal. The auxiliary E.M.F. employed was the normal, *i.e.*, 6·5 volts, and was practically constant. Had the auxiliary E.M.F. been raised a little at starting, and the shunt circuit closed sooner, say at about 600 revolutions, a rather more gradual speed curve would have been obtained. Such fine adjustment is, however, quite unnecessary for practical purposes; it is, indeed, quite sufficient to directly close the shunt circuit at about two-thirds of the normal speed; the dotted curves remain much the same, the kick in the stator current curve is, however, more pronounced, and as nearly as could be observed the current rose momentarily to 68 amperes when the torque was kept nearly constant. In practice the torque required decreases as a rule with the speed, so that in reality the current would not rise to 68 amperes, and it is thought that the dotted curves represent more nearly the conditions which would obtain in actual practice if the shunt circuit were closed at two-thirds of the normal speed without the interposition of resistances.

It remains for us to deal with a modification of this motor, but capable of developing without increase of pressure at the terminals, and without starting apparatus of any kind, a torque at starting at least four times the normal on circuits of 50 periods. This machine is particularly well suited to do duty where a series characteristic is required, and since it can be converted into a constant speed machine at any time and with the greatest ease, it is also suited for ordinary work, more particularly, however, for elevator service on high periodicity circuits, and where specially great starting efforts are needed, together with freedom from racing.

It has been shown that the rotor winding in the axis D D is made use of in the shunt induction machine as the field winding. It is clear that if it can be used as a shunt-exciting winding it can be also used as a series-exciting winding. The author has found that, for the purpose of starting and speed regulation, a very marked improvement can be secured by connecting the rotor winding along the axis D D in series with the field winding S_2 disposed on the stator, and also in series with the transformer winding S_1. Going a step further, he also connected the winding S_3, providing the auxiliary E.M.F. for improving the power factor when working at a constant speed, in series with the windings already enumerated. These connections are shown diagrammatically in Figs. 27 and 28 for both directions of rotation.

By this change of connections the nature of the machine is not altered in any way; it is still nothing more than a series induction motor. As before, the stator group S_1 induces the armature current, but instead of all the motor field winding being disposed on the stator, part of it is also disposed on the rotor; the rotor winding itself in the axis D D doing duty as such.

The winding S_3 has a small E.M.F. generated in it which is co-phasal and of the same direction as the E.M.F. impressed on the motor, and consequently increases the total active E.M.F. The advantages secured are manifold. As before, the machine can be

designed to take as little current as may be desired on the first point of the starting-switch without the help of external resistances, transformers, and the like, and with less turns in the group S_2 than were previously required. Whereas before, when the rotor field winding was not in series with the stator field winding, the starting torque fell to zero as soon as all the stator field winding was cut out, now the

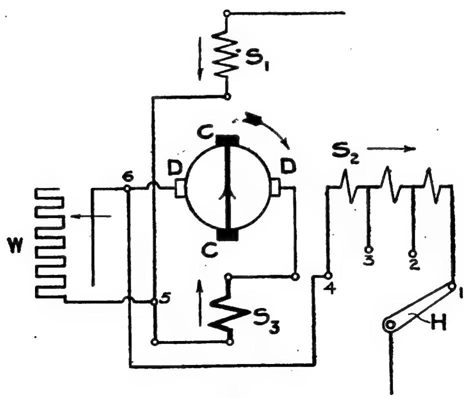


FIG. 27.

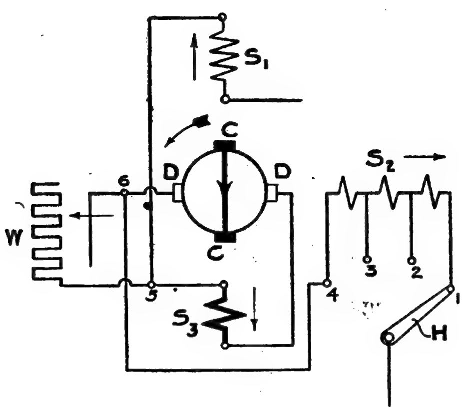


FIG. 28.

starting torque reaches a maximum at that point. This last difference is of extreme importance for heavy work, and particularly so for lift work. This modified motor also shows a very much better power-factor when running as a series machine, the reason being that the E.M.F. (E R) generated at the D brushes is nearly opposed in phase to those components of the E.M.F. impressed on the terminals which go to balance the E.M.F.'s of self-induction generated in the motor

windings. The phase of the E.M.F. due to S_3 tends to coincide more and more with the motor field as the motor speed increases. The field brushes D, which before were idle during the greater part of the starting period, are now made use of from the very beginning and with the greatest benefit. As to the conversion of the motor into a shunt induction machine, it is almost simpler than before; all that is necessary is to short-circuit gradually, or suddenly, the points in the connections marked 5 and 6. If a resistance W is connected in parallel to these points, the speed can also be regulated to some extent by its help. The higher the resistance, the nearer will the characteristic of the motor approach to a series characteristic. A reduction of this resistance tends to bind the motor more and more to its natural constant speed; decreasing its speed if the same happens to be above the natural, and increasing it if it happens to be below the natural.

For the purpose of short-circuiting the points 5 and 6 at approximately the natural or synchronous speed, the author has devised a very simple centrifugal arrangement which can be fixed on the motor-shaft outside the frame and which secures a quick make and brake; in this way the controllers for lift work, for example, are greatly simplified. Such a short-circuiting device will operate well within 15 per cent. (up or down) of the prescribed speed, so that every shock is absolutely avoided. It is only necessary for the various windings which have been enumerated to be in series relation to each other; they need not be connected in series directly, it being possible and sometimes very useful to interpose series transformers.

As an illustration of the advantages to be gained by this improved means of starting, some tests carried out on No. 3 motor are graphically reproduced in Fig. 29. The transformation ratio from stator to rotor was 2·6 to 1. Notwithstanding that no transformer was used to feed that part of the field winding which is disposed on the rotor, the connections being exactly as shown in Fig. 27, the improvement secured is very marked indeed—with the same starting current a 27 per cent. greater torque was obtained; in other words, a torque 2·5 times the normal, with rather less than twice the normal current, and this with a small 8-pole motor on an 85-cycle circuit. Apart from this, the properties of the motor as a series induction machine (full lines) are vastly improved, the maximum power factor rising from 0·82 to 0·975, the maximum efficiency from 57 to 66 per cent., and the maximum B.H.P. from 6·56 to 7·6.

The dotted curves show what would happen if the centrifugal device referred to acted at 15 per cent. below the normal speed. In order to carry out this test the rise of speed was watched on a tachometer, and the points 5 and 6 were short-circuited at a speed of 1,100 revolutions. The transition to shunt operation is even more perfect than in the previous case.

It is not proposed to deal more fully in this paper with the performance of this motor as a machine with a series characteristic; enough has been said to show the possibilities in that direction, but it might be added that traction motors have been built and tested, giving excellent

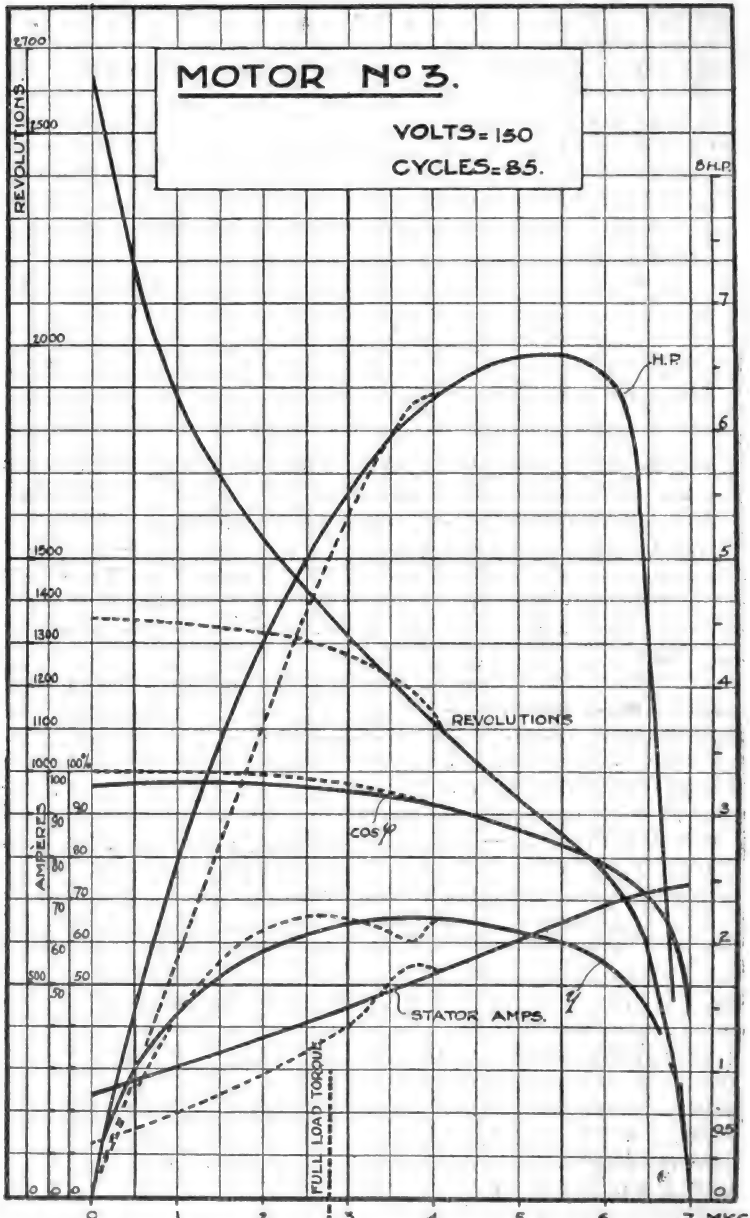

MOTOR No 3.
VOLTS = 150
CYCLES = 85.
REVOLUTIONS.
AMPÈRES
B.H.P.
H.P.
REVOLUTIONS
cos φ
η
STATOR AMPS.
FULL LOAD TORQUE
MKG.

FIG. 29.

results. These machines have a very high power factor and commutate well. Comparatively good efficiencies have also been secured; that of a 60-B.H.P. motor at 500 revolutions reaching 82 per cent. for 40 B.H.P. and 86 per cent. at full load. The author hopes to shortly

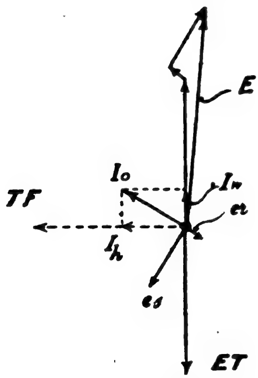


FIG. 30.

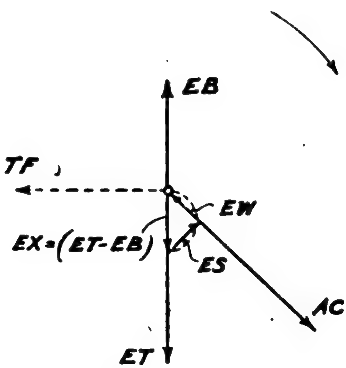


FIG. 31.

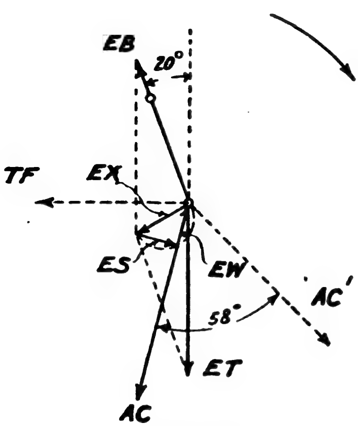


FIG. 32.

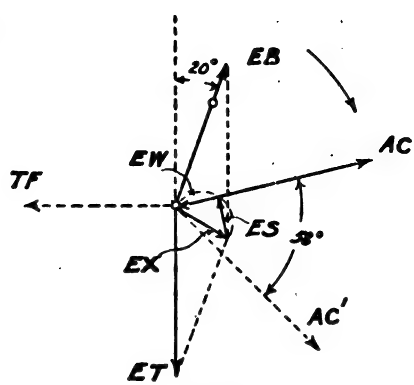


FIG. 33.

have an opportunity of publishing a more detailed account of this special work.

In order to throw additional light on my views with regard to the phase compensation of these motors, I propose, with the help of a few simple diagrams (Figs. 31–33), to approach the subject from another point of view, and, having now patented most of the novel designs which I have been able to evolve from my theory, I can also add a few remarks relating to the general theory of the shunt induction motor which, of course, also apply to the motor under consideration.

The conditions which are of the greatest interest are those prevailing

in the rotor along the armature axis. Let us assume, to begin with, that the back E.M.F. (E B) is, as regards phase, exactly in opposition to the working E.M.F. (E T). The conditions then prevailing in the rotor along the armature axis are shown in Fig. 31, where T F indicates the phase of the transformer field. The motor is supposed to run sufficiently slowly for the E.M.F. (E X), which in this case is equal to (E T — E B) algebraically, to have the value indicated. Now we know that the two other E.M.F.'s (E W and E S) which must be taken into account in this circuit are always at right angles to each other, and they will consequently meet somewhere on a half-circle described about the centre of E X and having a diameter equal to E X. It is easy to see that, under these conditions, phase coincidence between E T and the armature current A C can only be attained when the self-induction of the rotor along that axis is zero, and E X would then be in phase with A C. Supposing for the moment that E S could be eliminated, it would still be quite impossible to obtain in the primary or stator a power factor equal to unity. Of course E S can never be zero in a shunt induction motor, no more than the rotor resistances can ever be nil, so that for the case of Fig. 31, A C would never be in phase with E T, and this phase difference would be the greater the greater E S relatively to E W. With increasing load E X would have to become larger. This would necessitate a decrease of E B, and consequently a decrease in speed. In the case of a shunt induction motor this decrease would not be proportional to the increase of E X, because in these machines the motor field also decreases with the speed, and E B depends on the latter as well as on the speed. Then, again, with increasing load A C would have to increase, not only on account of the increase in load, but also for the reason that as A C increases it also lags a little further behind E T on account of E S, which, owing principally to increasing leakage, rises somewhat faster than A C, whereas E W only increases in the same proportion with A C if we disregard the increase of resistance due to heating. In order to fully recognise this fact it is only necessary to remember that E B is co-phasal with the motor field, and that the more A C lags behind E T the more the working current gets out of phase with the motor field, and therefore the greater is the armature current required for a given torque and with a constant motor field.

It is altogether clear that a shunt induction motor (or for that matter any alternate-current motor) in which the phase difference between transformer and motor field is exactly 90° can never be satisfactory. In such a motor, and without the help of external devices, the power factor can never be unity, and can only be made at all acceptable by sacrificing the efficiency; further, the output for weight must be small, for A C can never be in phase with the motor field. Yet the rotary field theories advanced to explain the action of the shunt induction motor lay stress on the desirability of as perfect a rotary field as possible; this, of course, can only be achieved when the phase difference between the two fields is exactly 90° and when they are equal in magnitude.

Let us turn now to Fig. 32. The motor field is here supposed to be leading T F by about 70°; A C, E W, E S, have been chosen of the same magnitude as before; this small change in the phase of the motor field, bringing with it a change of phase of E B amounting to 20°, has caused A C to move through about 58°, from A C′ to A C.

Here we obviously have a very much more favourable state of things. Under the conditions chosen, A C now *leads* E T, and it is clear how a corresponding and opposed component added to the stator no-load current will bring the resultant stator current nearer to the phase of the E.M.F. (E) impressed on the terminals of the motor, and it is also clear how, if desired, this resultant stator current can be made to lead E. Under these conditions power-factor unity can be obtained with as small a rotor resistance as desired, and therefore without for that reason sacrificing the efficiency. It is, however, important not to shift the phase of the motor field too far in the direction indicated, for if at full load the phase of A C still lags much behind the phase of the motor field, the machine will require a greater armature current for the same torque. In Fig. 32, A C is considerably out of phase with the motor field, but then the conditions in all these figures are much exaggerated in order to secure clearness, and it is quite possible in practice to secure extremely high power factors without introducing such a phase difference between A C and the motor field as to impair the efficiency. It is to be noted that whereas the phase difference between A C and E T, and A C and the motor field was practically constant in Fig. 31, it becomes variable as soon as E B ceases to be co-phasal with E T, the reason being that as E B increases or decreases, E X not only varies in magnitude but also in phase, and although at light loads A C may lead the motor field considerably, this phase difference decreases with increasing load.

Now, one of the methods described in the paper takes advantage of these very conditions in order to improve the power factor of these machines. In order to bring about the necessary phase displacement of the motor field an auxiliary E.M.F. is introduced into the field-circuit, and this E.M.F. is preferably so chosen as to lag by about 90° behind E R, which otherwise would alone be responsible for the motor field. The resultant of these two E.M.F.'s then sets up a field displaced as regards phase to an amount depending on the phase and magnitude of the auxiliary E.M.F.

Before leaving Fig. 32 it should be noted that over and above the advantages already enumerated, the same armature current can now be obtained with a smaller reduction of E B; this, of course, means that the motor now does its work with a smaller drop in speed. Superposing E B of Fig. 31 on E B in Fig. 32, the former would only reach to the small circle indicated on the line E B in Fig. 32. It is quite obvious that much more power can be obtained from a motor working under the conditions shown in Fig. 32 than from one working under those shown in Fig. 31, not only for this reason, but also because as the load increases A C now approaches the phase of the motor field instead of receding from it.

In Fig. 33 I have indicated what would tend to happen if the phase of the motor field were displaced in the opposite direction; even at no-load the motor might come to a standstill, or even tend to reverse its direction of rotation. The conditions shown are, however, entirely fictitious, because E B could not be maintained at the value allotted to it in the diagram, and would drop very rapidly with the speed, thereby slightly improving matters, inasmuch as the motor would not go so far as to reverse, but would only run very slowly, much against its will, to the detriment of its commutator, and taking a large current.

All this sounds very gloomy indeed for the ordinary shunt induction motor, such, for instance, as the squirrel-cage motor, because it would seem at first sight that the conditions in Fig. 31 must necessarily prevail in all such motors. Happily this is not the case, and in order to recognise this fact it is only necessary to study the no-load diagram of an ordinary transformer. This is shown in Fig. 30, and the main point to be noted is that when the E.M.F. of self-induction (*es*) of the primary winding is large as compared with the E.M.F. (*er*), representing the ohmic drop in that winding, then the transformer field T F lags by *more* than 90° behind the impressed E.M.F. (E). In an ordinary transformer with its almost perfect magnetic circuit, (*es*) will be very small, but in the induction motor, for instance, this E.M.F. will be very considerably greater already on account of the necessary air-gap. Whereas in an ordinary transformer E will lead T F by practically 90°, in an induction motor it will lead T F by more than 90°. Now in the motor-field axis of the shunt induction motor we have a transformer under no-load conditions, and the more the motor field lags behind the E.M.F. (E R), which is co-phasal with T F, the better will the motor be, not only as regards power factor, but also as regards output and efficiency. In this axis (*er*) should be as small as possible and (*es*) as large as possible, also the greater the phase difference between I_0 and T F the better. I think I can say that this is the most vital point in the design of these motors. Conditions approaching those in Fig. 33 are absolutely to be avoided; the conditions in Fig. 31 are unsatisfactory, and what the designer must aim at is to approach the conditions shown in Fig. 32 as nearly as possible. I venture to think that the whole crux of the matter lies in the phase relation between E T and E B, and there is no other theory of which I am cognisant which has brought out this most important fact.

I will not press this point further at this juncture; a careful study of these conditions must show everybody the further interesting deductions which can be derived therefrom, and these, I hope, will be of some assistance to those who design such machines. For the sake of completeness I will, however, call attention to another point which must be taken into consideration. The conditions I have just described with regard to the motor-field axis are practically constant for all loads, since the excitation for a shunt motor is nearly constant, and therefore the phase difference between T F and the motor field will be constant; but in calculating the resultant phase difference between stator current and the E.M.F. (E) impressed on the stator, account must be taken of

the fact that the phase relation between E and T F varies not only with the magnitude of the load but also with its nature. These conditions have been fully investigated for the ordinary transformer, for instance, by Steinmetz.* The phase of the impressed E.M.F. (E) being constant, the phase of T F will have to vary, but the relative phase relation between T F and the motor field will be preserved. The phase relations I am referring to will be exaggerated for the imperfect transformer with which we are dealing.

I have said before that the phase relation between A C and E T varies with the load; it is therefore not at once apparent that notwithstanding it is possible to obtain a nearly constant and high power factor for all loads, and with a constant phase difference between E T and E B. The diagrams (Figs. 34, 35, and 36) will, I trust, show how this

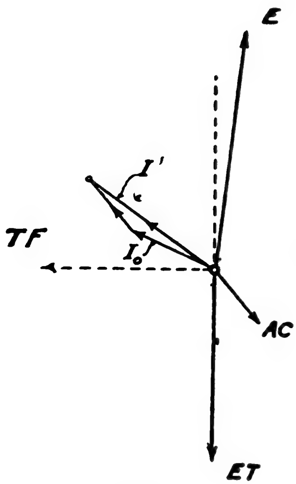


FIG. 34.

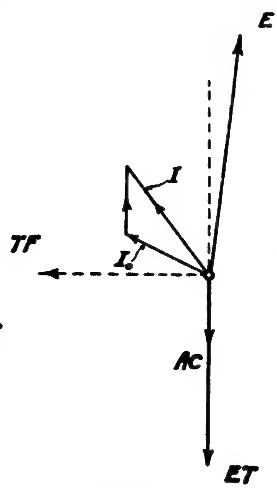


FIG. 35.

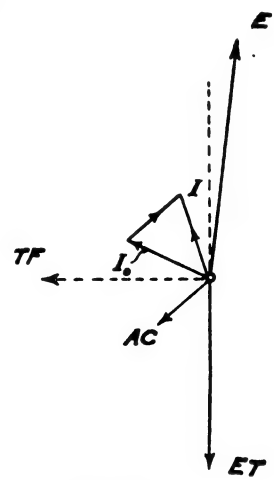


FIG. 36.

can be achieved. The three diagrams show the effect of a constant secondary current A C of varying phase on the phase difference between the resultant stator current (I) and the E.M.F. (E), for a constant stator no-load current (I_o).

Even at no-load there must be a certain armature current flowing in the rotor along the transformer axis in order to keep the motor in motion and indirectly supply the excitation for same; it is obvious from these diagrams that A C must be a leading current if I is to be even nearly co-phasal with E. It might be objected that at no-load A C ought to be so small that even if it were leading E T by very much it ought not to be able to bring I into phase with E. It must be remembered, however, that the more A C leads E T, the more it gets out of phase with the motor-field and, consequently, the more must

* "Alternating Current Phenomena," page 202.

A C increase, notwithstanding that the torque required at no-load remains constant. The result is that I not only decreases as the lead of A C over E T increases, but its phase comes into closer coincidence with E.

These conditions at no-load can be secured by choosing the phase relation between E T and E B indicated in Fig. 32. We have seen that the phase of A C in that diagram approaches that of E T with increasing load; a glance at Fig. 36 will show that if the lead of A C is reduced, whilst at the same time its magnitude is increased, the phase relation of I to E will remain much the same. As a matter of fact, it will vary to a certain extent, but for all practical purposes this method of phase compensation secures a phase difference between stator current and impressed E.M.F. which can be called constant, decreasing at first and then increasing with increasing load. It should also be noted that with this method of phase compensation the phase difference between E B and E T increases a little with decreasing speed, because E R decreases whilst the auxiliary E.M.F. remains nearly constant; this, of course, is an advantage, and tends to improve the power factor at the higher loads.

It may sometimes be necessary to make I lead E at no-load in order to obtain a high power factor at full load; these conditions are determined by the constants of the motor, and can be ascertained by calculation.

I should like to add a few words about sparking: I have shown in my paper that the reactance voltage only need be considered under the normal running conditions of this motor; we may take it that, just as in the continuous-current machine, this voltage is in phase with the armature current and can therefore be counteracted by the same means, *i.e.*, by the use of commutating poles. To be absolutely effective under all loads, these poles ought to carry windings disposed in series relation to the rotor currents the commutation of which they are to assist. This would be inconvenient for many reasons, and in practice sufficiently good results are obtained by making use of the corresponding stator current I. Commutating poles excited in this manner will not induce E.M.F.s absolutely in phase with the reactance voltage, but this disparity of phase will decrease with increasing load, and it is at the heavier loads that their help is mostly needed. No kind of commutating coils will, however, help to reduce any tendency to spark at the moment of starting, and at that particular stage nothing but a heavy armature current, weak motor field, and resistances between commutator segments and rotor winding, will be of the slightest use. Now, the use of resistances between commutator and rotor winding is detrimental to the efficiency of these motors once they have attained their normal speed. We have, however, ready means at hand for reducing this harmful influence to a negligible quantity by making use of the auxiliary revolving short-circuits indicated in Figs. 12 and 13. It is therefore quite easy to construct this particular motor for very large sizes, being able at the same time to guarantee perfect commutation. In this respect, as in the many

others already enumerated, it presents great advantages over other types of alternating-current motors.

DISCUSSION.

Mr. LLEWELYN B. ATKINSON: I think the thanks of the Institution are, in the first instance, due to the author for the very interesting and instructive paper which has been put before us to-night. The success which he has obtained is a success which has not been suddenly reached with a plunge. I know that the author has been working, often under very serious difficulties, at this subject steadily for the last eight or ten years, and I think we may all congratulate him that he has succeeded in bringing to a triumph the motor which he has put before us in this paper to-night. The author has alluded in the paper, in very generous terms, to my own work on this subject, and especially to a paper which I read in 1898 before the Institution of Civil Engineers.* At that time practically all explanations and theories connected with alternating motors rested on a discussion of a rotary field, which, I think, did a very great deal to retard the progress of design in electrical motors of the alternating-current type, because the method of reasoning is only really adaptable, without very forced ideas, to multiphase motors with symmetrically disposed currents. As long ago as 1888 I took out my first patent on alternating-current motors. That patent was based on the idea of a transformer with a rotating secondary coil, and with a magnetic field acting upon the wires carrying currents induced in that secondary coil. As long ago as 1888 a small machine of that kind was built. I recognised then the necessity of small air-spaces, and I carried it to such an extreme that probably that was what suspended those experiments, because the shaft of the machine used to bend so badly and touch the poles that we did not get much result out of it, and, as often happens with those things, if they do not go off well at first you put them on the shelf, intending to come back to them, and you never do come back to them. After one or two trials at this class of motor, there was brought over to England a little shunt-wound generator which came under my notice. It was intended to generate continuous currents, and was designed and made by M. Rechnieuski, in Paris. It was given to me in order that I might test the question of outputs and so on; and as a matter of interest, along with Mr. Ravenshaw, I carried out some experiments as to how it would work with an alternating current. We could not use it as a series machine or a shunt machine, and we found the only way to make it work was to connect the generator to the shunt coils, to short-circuit the brushes, to tilt them from the neutral axis, and then it ran round very beautifully, although it sparked viciously. Then came the question why it worked. At that time we were all charged up to the brim with the "repulsion" motor of Elihu Thomson, and it was such an easy thing to say it was a "repulsion" motor that many of us never asked any more questions. However, I came to the conclusion that we had a motor there which Mr. Atkinson.

* *Minutes of Proc. of Institution of Civil Engrs.*, vol. cxxxiii, p. 113.

Mr. Atkinson.

was analogous to a series motor, in which you pass a current into the armature only; you do not magnetise the field, but you tilt the brushes. Such an armature will then revolve and magnetise the field; parts of the turns are acting to magnetise the field, and the rest of the turns are revolving in the field. That was the explanation of the matter. From time to time I went on with this work, and among the men in this country whom I was able to interest in it were Mr. Edward Cowan and Mr. E. Still, who worked a good deal with me in experimental work on this motor, and with me built in 1896-97 a motor in Manchester which would be, in the terms of the nomenclature we are speaking of, a series induction motor, of which I have here some of the tests which were made then. They are interesting from the point of view of shewing what at that date we had obtained with a series induction motor with short-circuited brushes. The maximum power which we obtained was 4½ H.P., ranging from 0·69. With 4½ H.P. the efficiency was low, about 65 per cent., and the power factor was also low, about 57 to 70 per cent. But the interesting part is that we were able to get a very good starting effect. The 4½ H.P. that I mention corresponded to 18 lbs. weight at 1 foot radius by way of torque. I have here a test of 20 lbs. weight at 1 foot radius by way of torque, with exactly the same current in the armature as it took when running, showing that the current in the armature was not greater at starting—that is to say, when the motor was standing still—but giving this full-load turning moment, it was no greater than it was when running. That, of course, was a state of affairs that had not been reached with any of the squirrel-cage single-phase motors. We had a great deal of trouble with sparking to start with, but we got fairly good results eventually. I find that on December 13, 1897, Mr. Cowan wrote to me: "I think there can be no doubt the sparking troubles are at an end, as we have had very nice runs up to 3 H.P. without any serious sparking." The brushes, I may say, were taken out of stock, and belonged to some continuous-current machines. At this point, however, we were unfortunately obliged to drop the matter, partly for the reason that the particular facilities that Mr. Cowan, Mr. Still, and I myself had at that moment of carrying out tests came to an end, and partly owing to a difficulty which I think is quite worth mentioning, because it is very instructive on the question of the patent laws of different countries. It was this. Patents were taken out in England for this motor. At that time there was no sort of examination; it was quite a simple process; but when we came to Germany we were met with the statement that everything was known—there was absolutely nothing whatever novel about it, and only very limited patents were granted. With regard to America, I carried on a struggle with the examiners in America for two years, particularly with regard to one of the patents for compensating the phase of the supply current, not exactly in the way the author has mentioned, but in an analogous manner. The final letter I had from the examiners in the American Patent Office was to this effect: "It is not understood, from either the original specification or the amendment

filed, what the compensating winding is, or what it is intended to accomplish. It is not seen why this has no inductive effect on the armature, nor how it can regulate the phase of the current. Its object is not understood. Until the applicant has complied with the requirements of a full, definite, and intelligible description of his invention, the examiner is unable to take any action on its merits." Turning now to the paper itself, the author has shown two things. First of all, by an exceedingly clever design, on more or less known lines, he has succeeded in getting over the sparking difficulty. He has succeeded in so proportioning his parts that he has got fairly good efficiencies. But he has done more; he has succeeded in solving, in a remarkable way, the combination of a compensated motor—that is to say, one in which the power factor is brought to unity without condensers or other outside appliances, in a motor giving an exceedingly good torque at starting and a good efficiency. This idea of putting on an additional field was not altogether new to me, but I was trying to get it in another and very difficult way, and it was this: In order to bring the primary current into phase with the primary E.M.F., to give the secondary current a lead by making the armature rotate in a field in quadrature with the motor field. The difficulty is that, as the load varies, the compensating effect has to be varied very considerably to do it, and it is not easy to get that variation. I only hoped, in fact, to get an average effect. The author, by what to me seems almost a stroke of genius—because the thing is so simple when it is done in the way in which he has accomplished it—has not tried directly to bring the secondary current into phase with the primary current, but he has altered the phase of the motor field. Offhand I should have thought that the alteration of the motor field would have been a dangerous thing to try; but he has shown that it has the effect of so small an alteration in the phase of the field that it does not produce any deteriorating effect, and at once gets over the difficulty of the varying load question. The author has not, to my mind, at all exhausted in the paper the possibilities that are opened up by such a motor as this, though he has shown what it may do with lifts, and so on. His investigations have not arisen out of mine, and therefore he may claim the entire credit of the invention to himself, because I know that when I was working at the subject his own mind was working on parallel lines, quite independently of what I was doing. I venture to think that the paper which has been brought before us to-night will have a profound bearing on many questions of power distribution, and on none with a greater effect than on tramways and the big railway electrifications which are now coming before us. Mr. Atkinson

Mr. W. M. MORDEY: I am glad to take part in this discussion, not because I wish to discuss the theories which the author has put before us, but because it enables me to refer to tests I have recently been able to make with some of these machines. I happened to be in Switzerland recently, and on my way home I stopped at Basle and saw some of Mr. Fynn's motors in the works of Messrs. Alioth, who were good enough to arrange that I should make some tests. I was very pleased with what I saw. I have been looking for a long time to the Mr. Mordey.

Mr. Mordey.

removal of the reproach that 1-phase alternate-current motors cannot do everything that direct-current motors can do. The author has materially helped to remove some of the remaining difficulties. He and others who are working at the same problems have given us machines with the qualities of direct-current shunt motors as regards constant speed, or nearly constant speed, and motors with the qualities of series motors. I will give in the *Journal** the figures I got in a rather hasty test of a 6-H.P. motor which was run from no load up to nearly 12-H.P. Through its normal range of load its speed dropped only 100 revolutions. That would not be a bad speed-regulating performance even for a direct-current shunt motor. There was no movement of the brushes, and there was no attention to the machine at all. The power factor was nearly unity, falling a little at 100 per cent. overload—a very creditable performance, I think, for a machine

* TEST OF 6-H.P. FYNN 50-∿ 4-POLE MOTOR AT THE WORKS OF MESSRS. ALIOTH, BASLE, JANUARY 12, 1906.

B.H.P.	Revs.	Amps.	Volts.	V. × A.	Watts.	P. F.	Effic.	Amps. (a)	Volts. (v)	Collection.
—	1,528	18·7	140	2,618	2,450	·94	—	—	—	Fair
6·3	1,428	53	139·5	7,393·5	7,050	·95	·67	125	11	Good
7·5	1,408	59	140	8,260	8,000	·97	·7	120	11	„
8·7	1,355	71·5	140·5	10,046	9,500	·95	·68	117	—	Fair
9·8	1,310	81·5	139·7	11,385	10,750	·95	·68	115	—	Bad
11·8	1,220	120	140	16,800	15,000	·89	·58	—	—	Worse

Remarks.—Fixed brushes throughout. No adjustment of any kind. Load was a water-cooled friction brake on pulley with adjustable weights.

(*a*) and (*v*) were current + (brush) volts in short-circuit at circuit "A" in diagram.

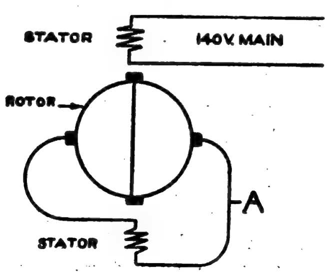


FIG. A.

for such a power. The collection was good—at the overload, I think, not worse than a direct-current motor overloaded to that extent. The starting torque I did not test. I was told the full-load starting torque was obtained at about full-load current. The efficiency was low, about 0·67 at full load. It should, however, be remembered that, unless a special point is made of it, one does not get a very high efficiency even with direct-current machines for that power. I doubt whether the commercial direct-current 6-H.P. motor has over 0·75 efficiency. I think we should look at that question broadly. We should be thankful for what we have got, and remember that by being able to use alternate currents we can usually get our energy to the motor with less loss than with direct current. We ought to credit the alternate-current motor with something on that account. For example, in all cases where there is a high-tension alternate-current transmission and a transformation by rotary converters, the 10 or 15 per cent. loss, or whatever it may be, in the rotaries ought to be set against the direct current. The causes of the lower motor efficiency are, I am sure, receiving Mr. Fynn's attention, and the attention of all makers of alternate-current apparatus. It is not only in this type of motor that there is room for improvement. None of the ordinary induction motors that are being sold in this country, either for one, two, or three phases, have as high an efficiency as they ought to have. This is, I believe, a result of working to designs made abroad, where less attention is given to this point than is usual here. In many cases the losses are avoidable losses. With these alternate-current commutator motors there is the added difficulty of the loss under the brushes. But there is another point which I think, perhaps, deserves more attention than it has received. In these days of very high magnetic densities, when people work up to 20,000 B. and more, we ought to do what we can to reduce the iron losses. We can reduce them in two ways: by keeping our densities low—that means, of course, a larger machine generally, or at least a larger armature diameter—and by using thinner iron. This is a matter to which I have often drawn attention, but I fear without any effect. People seem to have made a stand against using any iron less than about No. 28—that is, about 0·014 inch thick. It is quite practicable to go down, for example, to 0·01. I have here a curve, obtained from tests, giving the losses at 10,000 B., 50 $\sim$ at various thicknesses. At 0·008 inch the loss is 1 watt per lb.; at 0·026 inch, 2 watts per lb. Those are the total losses of energy in hysteresis and eddies under transformer conditions. If we take the higher densities that are often used much higher losses occur. I think manufacturers should put pressure on the rolling-mill people to roll thin iron for this class of work. Even after allowing for the greater space taken by insulation, it will be found that the use of such iron effects an appreciable economy of energy. Mr. Mordey.

Mr. F. CREEDY: I have read Mr. Fynn's paper with the greatest interest, as I have been working for practically a twelvemonth in company with the Rhodes Electrical Manufacturing Company upon exactly the same subject, *viz.*, the production of a satisfactory constant-speed Mr. Creedy.

Mr. Creedy. single-phase commutator motor. We have encountered precisely the same difficulties as Mr. Fynn, and have sought relief in very nearly the same way. However, before discussing this, I should like to say a few words about the repulsion motor shown in Fig. 5. For the past ten or eleven months we have been employing motors of this type for lift work, converting them when running into induction motors by means of slip-rings in the usual way. We have not found it necessary to use a variable number of turns on the field coil S_2, as one does not want several stops in the controller, and it is amply sufficient to design the field and transformer coils to give the specified torque while taking not more than the specified current. The controller is still further simplified if the field and transformer coils are left in series while running as well as while starting. This produces no ill effect, as it only shifts the transformer field through the angle a. I think Mr. Fynn's figures for the starting torque represent very well the results we have been obtaining, erring if anything on the side of moderation, with the coils S proportioned for full-load running in series with S_2. With special designs, however, it is possible to get twice full-load torque with less than full-load current: or three, four, or five times full-load torque with two to two and a half times full-load current. While on the subject of starting torque, I must confess that I see no reason whatever why Mr. Fynn's series motor, Fig. 27, should have a torque greatly in excess of that obtainable by a proper design of Fig. 5. In Fig. 27 the field winding is on the rotor, and there is no leakage between the field and the armature circuit. This, of course, is an advantage in small motors, and is the obvious cause of the improved torque obtained with motor No. 3, which naturally, as an 8-pole 6-H.P. machine, will have a high leakage factor. In designing a suitable compensating arrangement for small motors, one has to consider these two practical points: (1) it is undesirable to use a complicated stator winding requiring a complicated controller; (2) on account of the small diameter of the commutator, one cannot have the brushes at small angular distances apart. This necessitates the use of a wave winding. In small motors one need not use more than two brushes per rotor circuit.

For these reasons an arrangement of five equally spaced brushes on the commutator was adopted. Now, five brushes at 72° have the unique property of being equally adaptable for 2, 4, 6 or 8 poles, as can easily be seen on working out the spacing. The connections and controller for such a compensated motor are shown in diagram B. It can be started in one or the other direction by joining brush A to one of the opposite brushes C or D, the other two brushes B and E being open-circuited. When up to speed, B and E are joined to two of three tappings on the stator coil, producing a suitable E.M.F. for compensating, while A is joined to the remaining brush D or C. In practice these changes of connections are effected by a double pole two-way switch and a three-bladed centrifugal switch, practically the same controller being required as for the uncompensated motor with slip-rings. The results obtained with these motors are very similar

to those of Mr. Fynn. I think it might also be of interest to offer a few remarks on the commutation of these motors, especially at very high frequencies. No difficulty occurs with the commutation of these machines, at any rate up to 20 H.P. We have used single-turn bar windings of the two-circuit type throughout, except in the smallest sizes, even up to 20 H.P. 100 cycles. This applies to a motor with slip-rings. We have as yet no experience of 20-H.P. 100-cycle motors without slip-rings, but do not anticipate any difficulty, as the starting period is Mr. Creedy

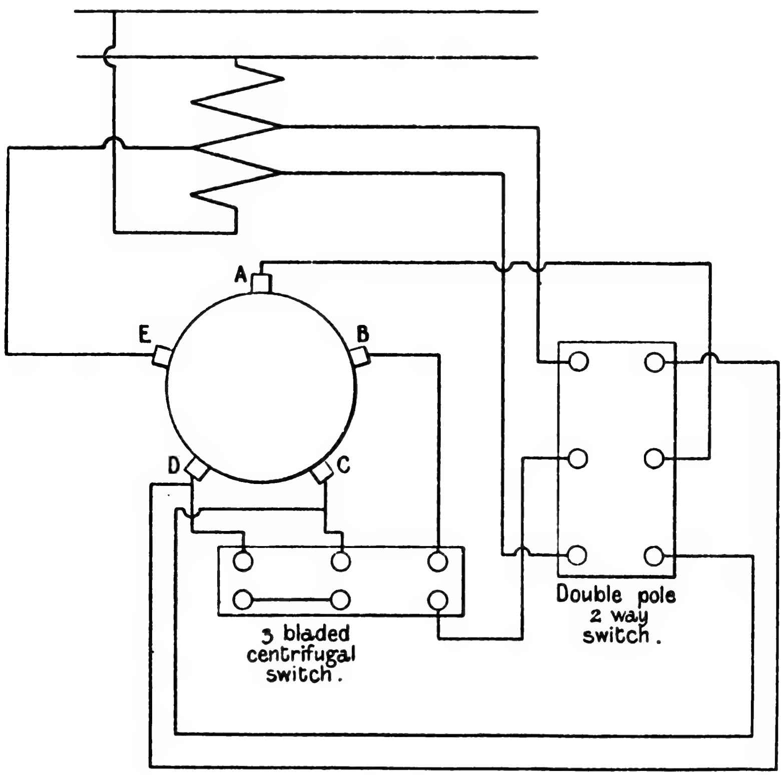


FIG. B.

universally acknowledged to be the most critical, and a motor which will start up and accelerate under load sparklessly as the slip-ring motor does, will usually run sparklessly at full load. It has been our experience that such unmechanical devices as high-resistance commutator connections are quite unnecessary in any properly proportioned rotor. In small machines, such as those whose tests Mr. Fynn describes, one may take extraordinary liberties with the commutation. I have myself succeeded in getting good commutation on a 1·5-H.P. 4-pole 50-cycle machine, having no less than six turns per commutator

Mr. Creedy. section, though I do not recommend the practice. I have even used copper gauze brushes on several small machines of about this size. I think that Mr. Hobart is hardly fair to the designers of the new types of single-phase motor in asking for weights at such an early stage. The firm with which I am connected have not paid much attention to this point, being of opinion that until the *type* of motor is settled with some finality it is more profitable to confine one's attention to the electro-magnetic design, rather than to design the intermediate types for light weight, although the methods used to lighten the polyphase motor are equally applicable to the single phase.

Mr. Jenkin. Mr. C. F. JENKIN: I wish first of all to congratulate the author on the very clear way in which he has dealt with an exceedingly difficult subject, as well as on the ingenuity of the means he has used for improving the induction motor. I take it that the point of the paper is the improved induction motor. The author has given us a motor which has a larger output, a higher efficiency, a better power factor, and less sparking than has been obtained before. This is a very great achievement. Although Mr. Fynn has mentioned it in his remarks to-night, I think a little more attention might have been drawn in the paper to the fact that the motor, as a repulsion motor, has all the defects of a repulsion motor at starting. Those defects are common to all commutator motors; they are due to the transformer effect producing a current in the short-circuited coils. Those defects, of course, exist in Mr. Fynn's motor exactly as in any other repulsion motor; they are not serious, but they must not be forgotten. At the beginning of the paper the author claims that he can give to his motor a series characteristic as well as a shunt characteristic. I should be very much obliged if he would explain in his reply how that is possible. At the end of the paper the author makes a sudden complete rearrangement of his connections, as is shown in Figs. 27 and 28, the result being to get a compensated repulsion motor. It is the ordinary Latour or Winter-Eichberg motor; it is a special arrangement without a transformer. This is not alluded to in the paper, although Mr. Fynn mentioned the fact in his remarks to-night. If the series characteristic motor which he promises us is merely the arrangement shown in his last figures, then there will be nothing new in it: it will be merely the ordinary compensated repulsion motor—a very good motor, but nothing better than those we already have. I hope he can promise us something better. In this connection I may point out that Mr. Eichberg * in a recent paper has shown a connection of his compensated repulsion motor which will make it work as a constant-speed or shunt motor. I should be glad to know whether the author considers that his arrangement is better than Eichberg's arrangement. It is difficult to compare the two without making actual calculations of the losses, but I am inclined to think that Mr. Fynn's motor will be better than Eichberg's motor.

Mr. Hobart. Mr. H. M. HOBART: The author has given in his paper a great deal of information about his type of single-phase motor. There are,

* *Elektrotechnische Zeitschrift*, 1904, vol. 25, p. 75.

however, two more points on which I should like some information. Mr. Hobart.
It seems a pity to disparage endeavours to get a good single-phase motor, for it is a very desirable end to attain. But we hear so much from the side of those who advocate single-phase motors, and so little from the other side, that it seems desirable to allude to certain difficulties. Mr. Mordey has spoken of a 6-H.P. motor which he tested at Basle which had 67 per cent. efficiency—that means 33 per cent. loss. The ordinary 6-H.P. polyphase or continuous-current motor would have something like 84 per cent. efficiency, or 16 per cent. loss. That is to say, the comparative loss is, in the single-phase motor, something like double. Therefore, if the means of ventilation and temperature rise permitted are just about the same in both designs, the

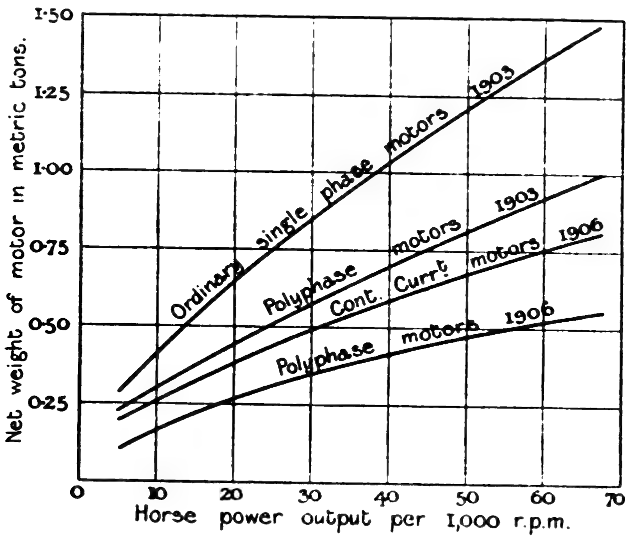


FIG. C.

single-phase motor must necessarily have something like twice the weight of the motor with the lower loss, whether it be continuous-current or polyphase. A motor of twice the weight would probably cost at least 50 per cent. more, and so until great improvements are effected we must make up our minds to pay something like one and a half times as much for a single-phase motor of a given output and speed as for a continuous-current or polyphase motor of the same output and speed. But we shall also have to put up with a less economy due to the lower efficiency. If higher efficiencies can be obtained, well and good; that will remove this difficulty. It is not at first obvious that great weight should be a fault in a motor. For stationary motors that would not, at first sight, seem to be of great importance, but from what I have said it is evident that great weight is closely associated with low efficiency. In the diagram (Fig. C) the upper curve is the single-phase motor of 1903, the very lowest curve is the

Mr. Hobart. polyphase motor of 1906, and the curve next above it relates to the continuous motor of 1906. The curve which is the third from the lowest is the polyphase motor of 1903. From what I have said it might be concluded that the 1906 polyphase motor is of far higher efficiency than the 1903 polyphase motor, because it has but half the weight. That is not the case. That is due to rapid developments in the latest practice with regard to the ventilation of motors. If we assume that all designers will at any one period use about the same means for ventilation, then, when you compare motors of this period, the efficiency hangs together with the weight.

The two points on which I should like further information are, first, the weights of some of the motors which Mr. Fynn has described in his paper, exclusive of slide rails and pulley, and, secondly, the corresponding ratios of these weights to the combined weight of copper and sheet iron, *i.e.*, of so-called "active" material. It would be of especial interest, also, if Mr. Fynn would give the weight of the 6-H.P. motor to which Mr. Mordey referred, and its rated speed, periodicity, and voltage. To better define the rating, the standard thermometrically determined temperature rise above surrounding air should be given, and this should correspond to the hottest accessible part when the motor is operated continuously at its rated load.

Mr. la Cour. Mr. I. L. LA COUR (*communicated*): Reference is made in the paper (Figs. 11, 12, and 13) to a new winding for compensated induction motors. This winding was tried by me in 1902,* but I abandoned it afterwards, since it would not give satisfactory results as regards compensating. I believe that this was due to the fact that the magnetising effects of the currents in the three legs of the star and those of the mesh (continuous-current winding) partly neutralise each other. On page 325 it is stated that a commutator motor as shown in Fig. 1 has all the characteristics of the asynchronous single-phase squirrel-cage motor. From my experience with this class of motors and with similar polyphase motors, however, I find a considerable difference between their behaviour and that of an ordinary induction motor. Commutator motors of that type behave more as unexcited synchronous motors, and the current diagram is distantly situated from the origin. Such motors generally hum and vibrate badly, so that it is hardly possible to run them for any length of time. The difference in behaviour from that of the ordinary induction motors is due to the fact that the reactance of the rotor winding is far from zero when the rotor runs at synchronous speed. This is experimentally verified by exhaustive tests† carried out by the writer. In the paper it is further stated that motors connected as shown in Figs. 27 and 28 give very good results as regards starting and speed regulation. This I have also found to be the case, and I took out patents (May 24 and November 21, 1904) on the use of an auxiliary winding (S_2 in the above

* A provisional patent of this arrangement was taken out in August, 1902, by O. S. Bragstad and I. L. la Cour.

† "Theory of Commutation of Direct and Alternating Currents," by E. Arnold and I. L. la Cour.

Figs.) for starting and speed regulation of compensated single-phase motors. The first experiments with such motors were carried out in June, 1904. Mr. la Cour.

Mr. V. A. FYNN (*in reply*): I was particularly glad of the opportunity afforded in publishing this paper, of publicly acknowledging my indebtedness to Mr. Atkinson's pioneer work. A good many people who have worked on this particular subject have omitted to mention his name, and we all know that the first steps in a new direction are always the most difficult. I thoroughly agree with Mr. Atkinson that the rotary field theory has done a good deal to retard progress, and the sooner it is abandoned the better. The sketch he gave us of his early work and successes, together with the trouble he experienced in securing patents, was interesting. With regard to this question of patents I have personally met with better luck, although it took me two and a half years to secure my main German patent, and, I think, eighteen months to secure my American one. I have had this advantage, that the examiners I have had to deal with were naturally very much better informed, and happily were willing to listen patiently to all necessary explanations. As will be seen from the introduction of my paper, I too had great difficulty in interesting people in these motors. Mr. Fynn.

The question of efficiency was mentioned both by Mr. Mordey and Mr. Hobart, and to a great extent Mr. Mordey's remarks anticipate and meet the objections raised by Mr. Hobart, so that my task is lightened. I will first of all answer as far as I can the questions put by Mr. Hobart; the motors, particulars of which I have given in my paper, are rated for a maximum temperature rise not exceeding 50° C. The net weights are 200 lbs. for motor No. 1, 265 lbs. for motor No. 2, and 660 lbs. for the 83-cycle No. 3 motor. I am not in a position to give any particulars of the motor tested by Mr. Mordey. I was not present at the test, nor have I any means of identifying the motor, but I fancy it is one of the early experimental machines. In my paper I have given some data which do supply some of the information Mr. Hobart requires. I have stated, for instance, that the addition of the improvements described by me raises the output of an ordinary single-phase shunt induction motor by 30 to 40 per cent.; I add that the addition of these improvements also raises the weight of the motor at most by some 15 per cent., because one of the end brackets has to be made larger, in order to accommodate the commutator and brush-gear which now becomes necessary instead of the lighter slip-rings, brush-gear, and short-circuiting device. This shows that the curve representing these new motors will fall below Mr. Hobart's single-phase 1903 curve. Then again, the data I have given were not obtained on motors in which the latest practice with regard to ventilation had been observed, so that further improvements can be anticipated in the immediate future. I trust very shortly to be in a position to publish full particulars of a new series of these motors. I cannot agree with Mr. Hobart that the efficiency of an ordinary commercial continuous-current motor of 6 B.H.P. is anything like 84 per cent.; it is much nearer 75 per cent., so that the comparative loss, even in the motor tested by Mr. Mordey,

Mr. Fynn. is only 32 per cent. greater than that of a continuous-current machine of the same size, and not 100 per cent., as suggested by Mr. Hobart.

I have made some 60-B.H.P. motors with an efficiency of 86 per cent. at full load, and this question of efficiency is at the present moment receiving my most earnest attention. I admit that I cannot hope to equal the efficiency of a corresponding continuous-current motor, mainly on account of the increased losses due to the alternating field permeating the whole frame of these single-phase motors (in most cases there are even two such fields), but I see no reason why such motors should lag by more than 5 per cent. behind continuous-current machines. Their weight efficiency will, I fear, also remain behind that of their continuous-current rivals, but all these differences will shortly be very much smaller than is now the case. When comparing a continuous with a single-phase commutator motor, it must never be forgotten that the former is in the prime of life, whereas the latter is only just out of the nursery. In a great many cases the use of the continuous-current motor, even with its present acknowledged advantages, is quite out of the question, whereas the use of a single-phase motor of the type I have described offers a most satisfactory solution. The existence of such a machine does not sound the death-knell of any other type, but simply opens out fresh fields for the application of electrical energy.

In his remarks about the starting performance of my motor, Mr. Jenkin is quite right. It does start as a "repulsion" machine, and if I did not dwell on the effect at starting of the E.M.F. produced by static induction from the motor field in the coil undergoing commutation, it is because I had nothing new to say on the subject. I have not found as yet any practical means for counteracting this E.M.F., and it is a difficulty which should occupy the attention of all designers, as its solution would be of immense advantage to all single-phase commutator motors. Mr. Jenkin persists in referring to a series induction motor as a "repulsion" motor; if he will once see that the motor I have described has nothing in common with a true repulsion motor, he will also find that all the suddenness of which he speaks in connection with the rearrangement of connections, as shown in my Figs. 27 and 28, entirely disappears, and the whole matter resolves itself into a gradual alteration from a series to a shunt connection. The motor shown in Figs. 27 and 28 is much more than a Winter-Eichberg machine. The only common feature is the means for improving the power factor when running as a series induction machine. The winding S_2 is a most important addition; not only does this additional field winding enable the current taken by the motor on switching-in to be reduced to any desired extent, but it enables its speed to be regulated within the widest range without the use of any auxiliary transformers or the like. Now that, I contend, is most important from the point of view of the manufacturer as well as that of the buyer, for the price is thus greatly reduced. Then, again, under otherwise equal conditions such a motor will, with a constant line pressure, start with a greater torque than could be obtained with a motor such, for instance, as shown in Fig. 14, because in Figs. 27 and 28 the winding S_3 raises the voltage applied to the motor, and it is well

known that the torque increases with the square of the voltage applied. Mr. Fynn.
As regards the motor shown by Dr. Eichberg in the *Elektrotechnische Zeitschrift* of January, 1904, to which Mr. Jenkin refers, it is really a compensated shunt induction motor such as I have described in my paper, and which I had discovered and protected as far back as 1902. But it is worthy of note that Dr. Eichberg in 1904 failed to recognise the real reason for the satisfactory operation of this motor as a shunt machine. If those who are interested will refer to his important paper in the *Elektrotechnische Zeitschrift*, vol. 25, 1904, they will find a diagrammatic representation of the motor in question on page 81, Fig. 63, and they will also find on that same page, lines 22 to 39 inclusive, the short description of the motor, a translation of which I give. Referring to his series arrangement, Fig. 54, Dr. Eichberg says: "It is easily seen from Figs. 55 and 56 that *the E.M.F.'s* across the exciting and stator circuits are of same or *nearly same phase* for all speeds. The reason for this is that with increasing speed E.M.F.'s are produced which reduce the difference of phase. It is therefore possible to derive the E.M.F.'s for the stator and for the exciting circuit *from the same transformer;* the E.M.F. applied to the stator should be increased with increasing speed, whereas the exciting E.M.F. should be decreased. At synchronous speed, or in its neighbourhood, one only *excites* the motor with a few volts. The Fig. 63 shows this disposition. . . ."

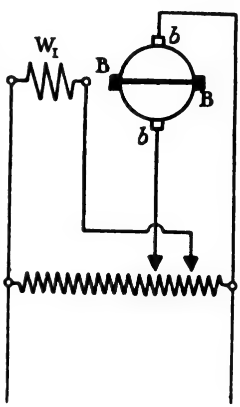


Fig. D.

Now a study of the diagram in Fig. 55 (Fig. 56 is only a simplified diagram of the same motor) together with the diagram of connections of Dr. Eichberg's series motor shown in Fig. 54 reveals the following. The line (0–3) represents E_{W_1}, the E.M.F. at the terminals of the stator winding, and the line (3–6) represents (*e*) the E.M.F. at the terminals of the series transformer and which is impressed on the exciting brushes, *bb*, of the motor. As can be seen from Dr. Eichberg's diagram, these two E.M.F.'s are really nearly of the same phase, and this apparently induces him to believe that by applying a co-phasal E.M.F. to the stator W_1 and to the exciting or field brushes *bb*, and deriving the two from the same transformer, he will obtain a motor with a shunt characteristic. I reproduce in my Fig. D his Fig. 63, with the addition of the letters just referred to. The fallacy of this conclusion is fairly evident. According to Dr. Eichberg's notation the flux produced by the stator winding W_1 is ϕ; this is the flux I refer to as the transformer field and which is co-axial with the brushes B B. The exciting winding produces a flux F, which I call the motor field, and which is co-axial with the brush line *bb*. These two fluxes should admittedly be in quadrature in space as well as in phase. If, as Dr. Eichberg proposes, E.M.F.'s of *same phase* are applied along both axes, how can they

Mr. Fynn. produce fluxes differing in phase by about 90°? What really happens is this: in Dr. Eichberg's series machine it is the phase of the *current* passing along the brushes *bb* which determines the phase of the motor field, and *not* the phase of the E.M.F. (e) impressed on these brushes by the series transformer. As this current is nearly in phase with the E.M.F. E_{W_1}, which is responsible for the transformer field, the two fields will be nearly in quadrature as regards phase. If a motor with a shunt characteristic is required, then the motor field must be excited by an E.M.F. approximately in quadrature with E_{W_1}. Such an E.M.F. is produced at the brushes *bb* by rotation in the transformer field ϕ, and in Dr. Eichberg's diagram is represented by the line $2nK\frac{\phi max}{\sqrt{2}}\,ii$. If these brushes are short-circuited this E.M.F. will supply a motor field of the correct phase, and we obtain the motor shown in Fig. 1 of my paper. This motor will have a shunt characteristic and a bad power factor. If an additional E.M.F. is included in this circuit, its phase being chosen equal or nearly equal to that of the E.M.F. responsible for the transformer field (here E_{W_1}), then the power factor of the motor will be improved in the manner I have described in my paper. This is exactly what Dr. Eichberg has unwittingly done. He was evidently under the impression that he was imparting a shunt characteristic to the motor in his Fig. 63 by connecting the armature or stator winding and the field winding in parallel across the mains (as is done for the ordinary continuous-current shunt motor), whereas he was only thereby improving the power factor of the machine. Such an arrangement of course only works satisfactorily near synchronism. By varying the auxiliary E.M.F. (co-phasal with E_{W_1}) which is impressed on the field brushes, a speed variation in restricted limits only can be achieved. The result of tests given by Dr. Eichberg in Fig. 64 naturally refers to a nearly synchronous speed. Dr. Eichberg derives the auxiliary or compensating E.M.F. from a transformer independent of the motor itself, whereas I consider it distinctly more economical to derive this E.M.F. from the motor itself. There is of course no difference of principle involved, and I have in my patents mentioned all these variations.

I cannot agree with Mr. Creedy when he says that it is not necessary to subdivide the S_2 winding in Fig. 5. Mr. Creedy's contention that one does not want several stops in the controller will no doubt be readily subscribed to by the manufacturers: but what about the station engineers, who after all have to be considered? I fancy they will greatly object, especially when they know that it is an evil with which they need not put up. My experience is that a motor which is designed to stand an overload of some 50 per cent.—as it ought to—will at starting take about twice its normal current if switched directly on to the mains. If Mr. Creedy's motors take less when treated in that way, it is because their overload capacity is less, or because he uses resistances in the brush circuit, for he says that he does not switch part of the winding

out after the motor has started. A current twice the normal on switching-in is much too high. Then again, if he follows the same rule and tries to design his motor to develop, say, one half normal torque and not take more than the necessary current when doing so, he will find that unless he switches part of the stator winding out after the motor has started he will not even get full load out of the machine. It is such considerations as these which lead me to the design I advocate. Of course, if Mr. Creedy converts a motor started as in Fig. 5 into a shunt induction motor by short-circuiting the rotor by means of slip-rings, then I agree that, apart from the power of the motor, nothing will be altered whether he leaves S_2 in or not. My contention was clearly stated on page 332, line 30 and following, and was to the effect that S_2 when left in had a detrimental effect in "shunt induction motors having their rotors short-circuited along two perpendicular axes," and I there referred to Figs. 3 and 4, which show no revolving short-circuits as used by Mr. Creedy. If he will try the experiment he will see that I am perfectly correct in all particulars. I have stated in my paper that when the winding S_2 was connected in such a way as to decrease the current in the circuit DD, then the power factor suffered, and if S_2 was reversed, then the power factor would improve slightly, but the current in the circuit DD would rise. My shunt motor and Dr. Eichberg's series motor both labour under one great disadvantage, and that is this: the rotor in both machines has to carry not only the armature but also the field current. Now those who have designed continuous-current traction motors know that it is quite difficult enough under such conditions to get sufficient copper into the continuous-current armature, although the power factor in such machines is always unity and their efficiency is admittedly higher. This problem therefore becomes much more difficult in the case of the alternate-current motor, in which the rotor copper has to convey not only the armature but also the field current. Of course, the ordinary series induction motor shown in my Fig. 5 only carries armature current in the rotor, but then its power factor is bad. I trust shortly to be able to give full particulars of a motor combining the advantages of both types. The starting torque of the motor in Fig. 27 is increased as compared with that of the motor shown in Fig. 5 because S_3 boosts the voltage at starting. The improved torque obtained when running the motor connected as shown in Fig. 27 is not due to the absence of leakage suggested by Mr. Creedy, but simply to the fact that the power factor of the motor in Fig. 27 is very much better. By taking the stator current through the rotor in the direction of the motor-field axis an E.M.F. is included in the motor circuit which is practically opposed in phase to the E.M.F.'s of self-induction set up in the various motor windings connected in series across the mains. The E.M.F. which is thus included in that circuit is the E.M.F. produced at the field brushes by rotation in the transformer field, and is of opposite phase to the latter. I do not quite see Mr. Creedy's point about spacing the brushes on the commutator when read in conjunction with his very correct statement that complications are undesirable. I never use more than *four* sets of brushes on my com- Mr. Fynn.

Mr. Fynn. mutators, and I fancy that surely is simpler than *five* sets. For all motors with an uneven number of pole-pairs the four sets can remain at 90°. If Mr. Creedy prefers to switch his motors on to the circuit without regard for the station engineer or the neighbouring light consumer, I can suggest a still simpler diagram of connections than his. The Figs. E, F, G, explain themselves; the two first show the starting, and the third, Fig. G, the running connections. I do not suppose that Mr. Creedy believes he is introducing an innovation by deriving the compensating E.M.F. from an auto-transformer instead of a transformer with separate primary and secondary winding. There is, of course, no saving or any other advantage whatsoever in his arrangement, for the simple reason that the exciting current of such motors is always many times greater than the stator current, and therefore that part of the stator winding which is tapped to obtain the auxiliary E.M.F. must be either overloaded to the point of running the risk of burning it out, or it must consist of heavier wire. There can be no doubt that it is simpler to use a separate winding as I do, and to make it of a section

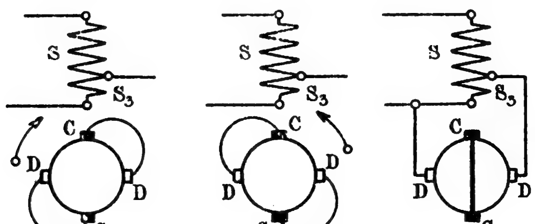


FIG. E. FIG. F. FIG. G.

suitable for the duty it has to perform. I am not surprised that the results Mr. Creedy obtains are similar to mine: he obtains them on the same motor. It is, as I have pointed out in my paper, quite immaterial along how many stationary axes you short-circuit such a motor, it still remains a shunt induction machine, and if you introduce the auxiliary E.M.F. by means of brushes midway between the short-circuited brushes, you improve the power factor in exactly the same way as has been described by me. The arrangement I use is merely the simplest and most effective of a great number of possible variations which do not depart from the spirit of the main idea. I wish it to be well understood that although I only read my paper in 1906, the motor therein described dates back to 1902. Now as to resistances between rotor winding and commutator segments, it is all very well for Mr. Creedy to say they are not necessary, but he himself admits that he has no experience with such motors above 20 B.H.P. Let him try to build high-power slow-speed motors such as the 60-B.H.P. motor I have referred to, and then see what he can do in the way of avoiding sparking at high frequencies and without the use of resistances.

It seems that Mr. la Cour has had most unfortunate experiences with these motors. The winding he refers to has also been patented

Mr. Fynn.

by me, and also in 1902; I have succeeded in obtaining very good results with it, and am satisfied that the patents are worth the money expended on them. The motors Mr. la Cour has experimented with must have been of a very poor design, for it certainly cannot be said that these motors suffer in any way from the disabilities mentioned by him. My motors run for any length of time as smoothly as ordinary induction motors, and this can be borne out by a great number of users. As to the E.M.F. of self-induction of the rotor, and I presume Mr. la Cour refers to the armature axis, that does not disappear in the single-phase motor, whether a squirrel-cage rotor or a commutator rotor be used. If Mr. la Cour means to compare these motors to polyphase machines, such a comparison is of course of no use whatever, as the two are totally different machines. I am glad that Mr. la Cour can agree with me at least as far as the good properties of the motors shown in Figs. 27 and 28 are concerned; I suppose that *these* motors do not hum and vibrate badly, and can be run for any length of time. I wonder if the fact that Mr. la Cour has taken out similar patents at all accounts for a good deal of this improved behaviour, for in other respects they differ but little from those described in the earlier parts of my paper.

In conclusion, I should like to thank you all, gentlemen, for the generous way in which you have received my paper, and I particularly wish to thank those gentlemen who have kindly taken part in the discussion.

The President.

The PRESIDENT: Gentlemen, I beg to propose a hearty vote of thanks to the author for his exceedingly interesting paper.

The resolution was carried with acclamation.

GLASGOW LOCAL SECTION.

RECENT ADVANCES IN WIRELESS TELEGRAPHY.

By J. ERSKINE-MURRAY, D.Sc., Member.

(*Abstract of Paper read December* 12, 1905.)

In the earlier part of the paper the chief systems in use were shortly described, and their methods of action discussed. Methods of discrimination between stations by the use of equifrequent electrical vibrators at the transmitting and receiving ends were explained, and instances given, the most striking example being that reported by Captain Jackson, R.N., the exact details of which are as follows: The *Vernon* received signals from Poldhu, 180 miles distant, on one mast, and at the same time sent signals to a ship 50 miles away by a separate aerial on another mast about 200 ft. from the first. The receiving was quite unaffected by the sending. Various forms of responders or detectors were then described, and mention was made of some recently patented systems which have not yet come into commercial use.

The Action of the Coherer.—The coherence of metal filings or surfaces was supposed at first to be due to electrical oscillations, and to be a test for their presence. I have never held the view that oscillations were necessary, believing that all that is required is merely an electrostatic field or difference of potential which causes the particles to join up in chains as do iron particles in a magnetic field.

That small particles do so in an electrostatic field has been shown by Robertson and others. When the ends of the particles come within a very small distance of one another a spark passes even if the voltage be low, and the welding takes place. The action is facilitated by very gentle intermittent mechanical shocks (tapping) just as in the case of iron filings in a magnetic field. Severe shaking, of course, prevents any chains from forming, or breaks up such as have been formed.

The action of a filings coherer thus takes place in two stages—first, the movements of the particles, and second, the welding.

That this view is correct has been amply proved by Dr. W. H. Eccles in an able experimental research which he undertook at my suggestion. He has also deduced a mathematical theory of the action which fits the results of experiment, and invented a method for testing coherers in the laboratory without the use of telegraphic apparatus.

Transmitters.—The electrical disturbance produced by the transmitter must be such that when it arrives at the receiver it produces, for however short a time, an appreciable difference of potential between the receiving aerial wire and earth. If the time rate of change of potential in the neighbourhood of the receiver were slow, there would never be an appreciable difference between the aerial and earth, as the electricity would change its distribution very slowly as a minute current of insufficient magnitude to affect the receiver. A sudden change of potential is therefore necessary in order that a signal may be recorded. It is the horse-power which matters, not the total amount of work done.

In the systems most in use at present, the method of obtaining this sudden and energetic discharge is that of Hertz, *i.e.*, the spark. It is Hertz's method of obtaining a sudden and oscillating discharge that is the essential in wireless telegraphy, not the fact that free radiations may be produced thereby. An alternator would be quite as suitable if it were capable of giving proper voltage and frequency, and, indeed, is being used by Fessenden.

Earth Connections.—When Marconi connected the lower ball of his Hertz radiator to the earth, he made the whole earth the lower ball. The earth and the aerial are the two conductors of the oscillator, which luckily is so unsymmetrical that it radiates very little indeed; in fact, the oscillations simply spread from their point of generation over the two conductors.

Under these circumstances he at once obtained signals at a much greater distance than he had previously achieved. He had, in fact, introduced a conducting connection between the transmitter and receiver, instead of depending on radiations through the non-conducting atmosphere. The electrical waves produced were no longer free, but were guided by the earth's surface as an alternating current is guided by a wire.

For the intense currents of very high frequency, which are used in wireless telegraphy, a good and widespread earth-connection is most essential. It is not necessary that it should be a conducting connection, however; an inductive connection, in which the earth's surface plays the part of one plate of a condenser, is quite as effective for high-frequency currents.

Wireless telegraphs may thus be divided into two large classes—(1) conductively earthed; (2) inductively earthed.

In the first class come practically all the systems mentioned except some forms of Lodge-Muirhead apparatus.

In the Lodge-Muirhead station at Heysham the earthing is inductive. One large insulated plate is about 3 feet above the earth, the other plate is 80 feet above the first. Taking the average difference of potential between the earth's surface and the lower plate as roughly one-half of that between the plates, we find that the dielectric current between the earth and lower plate is ten times as great as it would be through the spark-gap between the plates if the earth were not near. A conduction current in the earth's surface is thus induced

by the proximity of the lower plate, and the waves are guided by the earth's surface as in conductively earthed systems. Radiations approximately resembling on a large scale those used by Hertz would not be obtained by this transmitter unless it were placed at least 800 feet or more above the earth's surface on a perfectly insulating support. Conversely, if Hertz had placed one end of his vertical oscillator within a small fraction of an inch of a horizontal sheet of copper, he would not have obtained free radiations, but a result which on the proper scale would resemble the transmission at Heysham. It seems probable that the inductive earthing in this case will prove as effective as an elaborate conductive system, and at the same time the advantages of a very persistent oscillator will be retained.

The Limit of Distance in Transmission.—The propagation of a hemispherical electric wave, in which the lines of force have their ends on a conducting plane surface, has been investigated by Heaviside, and from a wireless telegraphist's point of view by Blondel. Neglecting the curvature of the earth, the form of the wave is approximately the same as would be produced by removing the earth and putting another wire downwards from the spark-gap, this wire being equal in length to the aerial, and oppositely charged at every moment. If the electric waves used in wireless telegraphy retained this form we should find that the currents resulting from their action on the receiving aerial would vary inversely as the square of the distance. This does not, however, agree with Duddell and Taylor's measurements—the only definite measurements as yet published—of the variation of the received current with distance. They find * from experiments made between a station at Howth and H.M.T.S. *Monarch* in the Irish Channel, that the current at distances beyond ten or fifteen miles varies in almost exactly simple inverse proportion to the distance between the stations. This result admits of no question, the experiments having been carried out most carefully and with wonderfully concordant results. We must, therefore, accept the fact and look for an explanation in some circumstance which modifies the hemispherical waves originally given out by the transmitter when they attain a radius of about ten miles.

I find that there is an explanation lying ready to our hand, which is based, not upon theory, but on the well-ascertained facts of the nature of our atmosphere. Put briefly, it is as follows:—If the earth were surrounded by a spherical shell of conducting material it is a well-known fact that the waves would not die away in proportion to the square of the distance, but would vary, for moderate distances, in inverse proportion to the distance itself. Now, recent researches on auroræ by Danish observers have proved that these occur sometimes as low as six miles above the earth's surface, and never at a greater height than sixty miles. An aurora is an electric conduction current; hence the layer of air between six and sixty miles above the earth is conductive.

Here we have, then, the explanation of Duddell's law of variation

* *Journal of the Institution of Electrical Engineers*, July, 1905.

with distance. The approximately spherical wave given out by the oscillator rises till it touches the conducting layer, then becomes annular, and travels outwards with a wave-front the area of which no longer increases as the square of the distance, but only in proportion to the distance itself, since the wave is confined by the parallel conducting surfaces above and below. Thus the only space-variation which causes diminution in strength is the increasing radius. There is, of course, in addition a frictional loss of energy which we shall consider later.

If we take the curvature of the earth into account, and proceed to trace the variation of the wave-front at greater distances than those of Duddell's experiments, which only extended to sixty miles, we find from simple mathematical, or rather geographical, considerations that the radius of the circle in which the wave-front cuts the globe is directly proportional to the sine of the angle at the earth's centre subtended by the arc of the surface between the transmitter and the wave-front. This agrees with Duddell's law because for small distances $\sin\theta$ is nearly equal to θ. For greater distances, however, the divergence becomes less and less, and at distances beyond 6,000 miles, *i.e.*, beyond $\theta = \pi/2$, the waves converge, and the current should increase with distance. This is true on any theory, as the wave-front is becoming a smaller and smaller ring, continually converging from all sides towards the antipodes of the transmitting station.

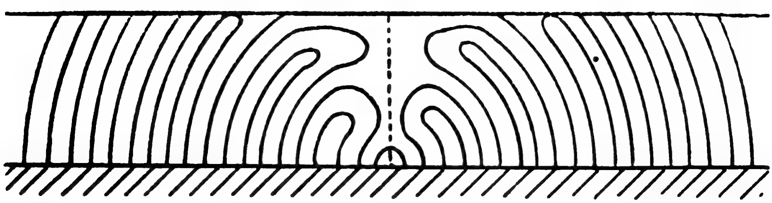


FIG. 1.

The equation for the received current is thus of the form :—

$$c = \frac{C}{\sin\theta} \text{ ; } \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad \text{(A)}$$

where c is the received current, θ the angle defined above, and C a constant.

Fig. 1 gives a rough representation of the lines of electric force as they spread from the transmitter outwards.

The above law of variation of the received current with distance is obviously not complete. We have so far supposed that the lowest layer of the atmosphere is a perfect dielectric, and that the earth and upper atmosphere are perfect conductors, *i.e.*, that no dissipation of energy is involved, the decrease of current being simply due to increase in area of the wave-front.

We must now take account of frictional losses, in order to com-

plete the law as far as possible; though with the data at present available only a rough approximation can be attempted. It will be possible to amplify the equation when further measurements have been made, and to determine more exactly the functions and constants involved.

The first indication of a true frictional dissipation of energy in transmission was found in Marconi's discovery that messages could be received at much greater distances during the night than by day. There cannot be much difference between the divergence variations by night and day, as the earth does not change its shape; this phenomenon has therefore to be explained by some difference in the electrical properties of the transmitting media. Now the conductivity of the earth cannot be seriously altered by the sun's rays; the atmosphere, however, may be much affected. Cosmical Science has made many striking advances lately, and it is now practically certain that streams of electrified particles, resembling the cathode rays, are ejected from the sun with a very high velocity. These penetrate the earth's atmosphere on the day side, electrifying it, and at the same time ionising it, thus rendering it more conductive. During the night equilibrium becomes slowly restored, and towards five o'clock in the morning a very marked minimum of atmospheric electrification has long been known to exist. The time at which signals go furthest thus coincides with a minimum conductivity of the lower layers of the atmosphere, while greater conductivity of the lower layers during the daytime coincides with greater difficulty in transmission.

Now an electric wave must have either an all-dielectric medium or a dielectric bounded by conductors; it cannot penetrate far through a conductor. Thus if all the atmosphere were conductive the wave would travel only a very short distance before being dissipated by resistance, and transmission to a great distance would be impossible. The conditions would be similar to an attempt to transmit current along a concentric cable with bad insulation between the conductors. The good insulation is just as essential as the conductors. We may take it, then, that during the night the lowest ten miles of the atmosphere is a good dielectric, while during the day it becomes slightly conductive.

To obtain a rough estimate of the amount of this dissipation we may take Mr. Marconi's statement that 500 miles during the day is equivalent to 1,000 by night. The variation is not so noticeable at short distances, being in this case so very much less important than the divergence, though it is distinctly traceable in Duddell and Taylor's results.

Let us assume that the law of divergence is that given above—Equation (A)—*i.e.*, that the undissipated current would vary inversely as the sine of the angle between the places, or approximately, for the distances under consideration, inversely as the distance along the earth's surface.

We then have Duddell's law—

$$C \times D = \text{constant}$$

where C is current received, and D is distance between the stations.

Now assume as a first approximation that there is no dissipation at night; then the current lost, by divergence only, between 500 and 1,000 miles at night is all spent by dissipation during the day before 500 miles is reached. Again, the divergence alone between 500 and 1,000 miles would reduce the current to one half, since 1,000 is twice 500. Therefore the current at 500 miles during the night is twice the current which will just work the receiver. The current lost by dissipation during the day throughout 500 miles is therefore equal to that which will just work the receiver. We have thus obtained an approximate value of the dissipation from Mr. Marconi's experiments. If we call the minimum working receiver current of Mr. Marconi's receiver M, then the current lost through dissipation is roughly M/500 per mile.

This dissipation is no doubt a function of the distance, the form of which I hope to be able to determine later. It is also, of course, a function of the state of the atmosphere, as regards electrification, and varies from a minimum in the very early morning to a maximum in the evening. In the meantime we may take M/500 as a rough approximation to its average mid-day value, under the circumstances considered.

The approximate equation $c = C/\sin\theta$ for propagation of signals then becomes—

$$c = \frac{C}{\sin\theta} - \frac{M}{500}d \quad . \quad . \quad . \quad . \quad . \quad . \quad (B)$$

where—

$c =$ received current,

$C =$ a constant,

$M =$ minimum current which will actuate receiver,

$d =$ miles distance,

and—

$\theta =$ angle subtended at centre of earth by arc d.

Now since $d/3500 = \theta$, approximately, since the earth's radius is 3,500 nautical miles, $\therefore$ $d = 3{,}500\,\theta$.

To determine C from (A) we notice that $c = C$, if $\sin\theta = 1$, *i.e.*, if $\theta = \pi/2$. C is thus the value of c at 5,400 nautical miles, or an earth quadrant from the transmitter during the night, *i.e.*, when *no* dissipation. We may state it as $C = kM$ if we like to take M as a unit, *i.e.*, the undissipated current at 5,400 nauts. is k times that necessary to work the receiver.

The equation then becomes—

$$c = M\left(\frac{k}{\sin\theta} - 7\theta\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (C).$$

To find the limit of distance with any given power we must have $c = M$, *i.e.*, the current at the receiver is just the smallest possible working current.

The equation (C) then becomes:

$$1 = \frac{k}{\sin\theta} - 7\theta . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (D)$$

or—

$$k - \sin\theta\,(7\theta + 1) = 0 \quad . \quad . \quad . \quad . \quad . \quad (D^1)$$

The number seven in this equation is only a rough approximation, suitable to the case under consideration. It should properly be replaced by some function of θ.

Let us now consider Duddell and Taylor's results for shorter distances in the light of this explanation.

Remarking on the slight decrease in the product $C \times D$ at long distances, they suggest reflection from the Hill of Howth as a cause, mentioning that another possible, but apparently less probable, explanation is that the cross-channel runs were made in damp, misty daylight, while the up-and-down channel course was made in the night and early morning with a clear frosty atmosphere. To me this latter suggestion is far more probable than the first. We know that such a difference exists from Marconi's results. It is worth while to attempt to derive it from Messrs. Duddell and Taylor's measurements. We may take from their curves the following data, comparing the day and the night experiments.

(1) *Night.*

"MONARCH" COMING SOUTH TOWARDS HOWTH.

Distance off Howth	...	18	...	36	Miles
$C \times D$	...	3850	...	3820	Micro-amperes $\times$ Miles.

Thus at 18 miles the current was 214 mA., and at 36 miles 106·1 mA.

Now, by divergence alone the current would at 36 miles have been one half that at 18 miles, *i.e.*, 107 mA. The dissipation loss is thus 0·9 mA. in 18 miles, or roughly 0·05 mA. per mile on 214 mA.

(2) *Day.*

In a similar way we may obtain by averaging curves, representing the same quantities on the voyage to Holyhead and back during the day, the value 7·2 mA. lost between 30 and 60 miles off Howth. This amounts roughly to 0·24 mA. per mile on a maximum current of 120 mA. Reducing the result given in (1) to suit this maximum current, we see that the dissipation by night is to that by day in the ratio of about ·025 to ·24, *i.e.*, the dissipation during the day is approximately ten times as much as at night.

Messrs. Duddell and Taylor attempted to measure the day and night variation between Howth and Kingstown, but did not find as much as 1 per cent. difference. This was natural, as these points are only about six miles apart, hence the total dissipation was very small in both cases. The difference of the values for night and day which I have deduced above would barely amount to 1 per cent. of the total in five miles.

Comparing the value of the dissipation determined from Marconi's experiments with that obtained from Duddell and Taylor's, we find that they are of the same order of magnitude. Nearer than this we cannot at present go, since the minimum working current of Marconi's long-distance receiver is not known.

In the present communication it is impossible to develop the subject further; I hope, however, that I may have an opportunity later of amplifying and substantiating the main framework of the theory

which I have given. Doubtless it is very rough, and in many parts incomplete, but it will, I hope, form a foundation for a more thorough explanation of wireless telegraphy.

It has been shown experimentally by J. J. Thomson that the conductivity of rarefied air, at a certain pressure, for electrodeless discharges, is as great as that of a 25 per cent. solution of sulphuric acid, and that a layer of such air half an inch thick forms a perfect screen for electric waves. A layer of air at this pressure must exist in the atmosphere at a very moderate height.

The same experimenter has also proved that there is a critical pressure at which the air becomes conductive. Under greater pressures it is practically an insulator, and at smaller pressures a good conductor. The commencement of the conducting layer in the atmosphere is thus sharply defined.

If an electric wave be a cylindrical shell of constant height between parallel conductors, the surface density, and thus the displacement and electric force, will vary inversely as the diameter of the cylinder. The energy per unit volume varies as the product of these quantities, and will therefore vary inversely as the square of the diameter, and be uniform throughout the shell. In the case of a hemispherical wave of the type considered the distribution of energy is not uniform. At the base the limiting form of the wave is cylindrical, as in the previous case, and its energy is the same, while in the vertical line through the origin the energy is zero. Either type of wave will therefore agree with the results obtained by Duddell and Taylor, but the facts as to the conductivity of the upper atmosphere, and the variations in dissipation, noted above, are in favour of the cylindrical theory.

DISCUSSION.

Professor F. G. BAILY: I have recently drafted out some views on the subject of insulated ground plates, and being now forestalled in the matter by Dr. Murray, with whose views I thoroughly agree, I will content myself with a few words in amplification of the paper. I am of opinion that the recent discussions about insulating the earth plate are quite beside the mark. Oscillations or reversing charges set up in an insulated plate, the distance of which above the ground is much less than the diameter of the plate itself, must necessarily be repeated by induction very completely on the surface below, unless the latter is of unusual dryness. Hence such a plate will be substantially equivalent to a plate in efficient contact with the ground. If the earth contact is poor, there will be part conduction and part induction, or the phenomena of a leaky condenser. Energy will be wasted in the resistance of the conducting path, and the efficiency of the transmitting system will be diminished. This appears to me to be the explanation of recent experiments that have been published. Attempts have been made to prove from the above phenomena that these waves are purely air-borne Hertzian waves, since contact with the earth may be actually harmful, Professor Baily.

Professor Baily.

but it does not appear that any such deduction can be made. Earth transmission can be as easily brought about by an insulated ground plate as is submarine cable signalling through the terminal condensers. I am in accord with Dr. Murray that the earth plays some part, and perhaps an important part, in the transmission of signals, especially over long distances; but crucial experiments on a suitable scale are difficult for a private individual, and calculations of decrement are unreliable. The author's proposal to press the upper layers of the atmosphere into the service is both ingenious and daring, but in view of the scantiness of our knowledge, both of the upper layer and of the phenomena of long-distance wave transmission, criticism of the theory is hazardous. The lines of force due to the travelling charges cannot, I think, be arranged satisfactorily without the assistance of the conducting upper layer. If the latter exists with this assumed conductivity, it will not only retain in our atmosphere the waves of mundane origin, but will screen us from waves due to outside sources.

Professor Jamieson.

Professor A. JAMIESON : I would like to show and explain the circumstances under which the exhibited original Kelvin siphon recorder and Morse tape signals were received by Mr. Maskelyne. These intercepted or trapped signals were picked up some 40 miles from Poldhu by Mr. Maskelyne's own receiver, although not intended for him, but for Mr. Marconi, who was on a voyage to Italy. No doubt means have been devised, since these signals were received, for preventing outsiders intercepting or receiving readable signals between friends, but are these means thoroughly successful under all circumstances ?

Mr. Mavor.

Mr. SAM MAVOR: Can Dr. Murray state the amount of power necessary to transmit signals across the Atlantic from the tower at Machrihanish ?

Dr. Erskine-Murray.

Dr. ERSKINE-MURRAY (*in reply*): With regard to the dryness of the land, I may say that in Damaraland the Germans have five stations working, and they have been increasing the number of their stations for the last two or three years. They had at first great difficulty as regards the earthing, but have overcome this by using an inductive earth. Damaraland is perhaps the driest tract in the whole world. They have five stations over a total distance of 680 kilometres, and are keeping their communications entirely open. With regard to Professor Jamieson's remarks, there is no doubt that Mr. Maskelyne intercepted signals, and that there was no difficulty in tuning his apparatus to pick them up. I do not think that anyone would say that one cannot pick up signals, but it is better to arrange that one does not. Any number of stations can be arranged so as not to interfere with each other, but if one is intent on picking up somebody else's signals it can be done, just as in wire telegraphy, though not so easily. I have no exact figures with regard to the power in the Transatlantic stations, but I understand that from 60 to 80 H.P. will be used at Machrihanish, although this is practically a guess. I believe there is to be 200 H.P. in Marconi's new Transatlantic stations.

BIRMINGHAM LOCAL SECTION.

TWO NEW ELECTROLYTIC METERS.

By S. H. HOLDEN, Member.

(*Paper read December* 13. 1905.)

ELECTROLYTIC meters may be divided into two classes: those in which the whole current passes through the electrolyte, and those which are shunted by a metallic conductor. The former are of the simpler construction and theory, but practical considerations render the latter class the more desirable generally. The two meters to be described are both developed from the oldest and simplest form of electrolytic meter, viz., the gas voltameter employed by Faraday, but one belongs to the unshunted and the other to the shunted class.

Taking the simpler, or unshunted pattern, first. In all full descriptions of the use of the old gas voltameter, certain inherent errors and defects are referred to, such as the formation of persulphuric acid and ozone, which vitiate the measurements, and the troublesome necessity of making allowances for temperature and pressure when determining the volumes of the evolved gases. The chemical defects are partly overcome by using phosphoric acid as electrolyte with platinum electrodes, or, better still, caustic soda solution with nickel electrodes, as suggested and used by Oettel. In order to overcome the difficulties of gas measurement Bunsen suggested that the electrolyte should be weighed and its loss of weight used as a measure instead of the volume of the evolved gases. It is Bunsen's suggestion which has been embodied in the first of the meters. As early as the year 1882 electrolytic meters were suggested in which an electrode was suspended from a spring balance, its alteration in weight being indicated thereon, and the dial of the balance being graduated in ampere-hours or other units. Of recent years spring balances for commercial purposes have been brought to considerable perfection, and it was felt that they were sufficiently reliable for the purposes of an electricity meter.

Fig. 1 shows in diagrammatic form the working parts of a meter constructed on what may be called Bunsen's plan. A is a thin iron vessel with an ebonite lid. Within this vessel is a solution of caustic soda and a pair of sheet nickel electrodes, BB. A small hole is left in the lid for the escape of gas. The whole vessel is supported upon four springs, two only of which are shown, and marked C^2. Attached to the

front of the iron vessel is a light rack, H, working into a pinion, F. This pinion carries a hand or pointer moving over a graduated dial. Part of this dial is broken away to show the gearing more clearly. Guide levers *aaaa* attached to the case and to the top and bottom of the iron vessel ensure its remaining central. Light flat springs, JJ,

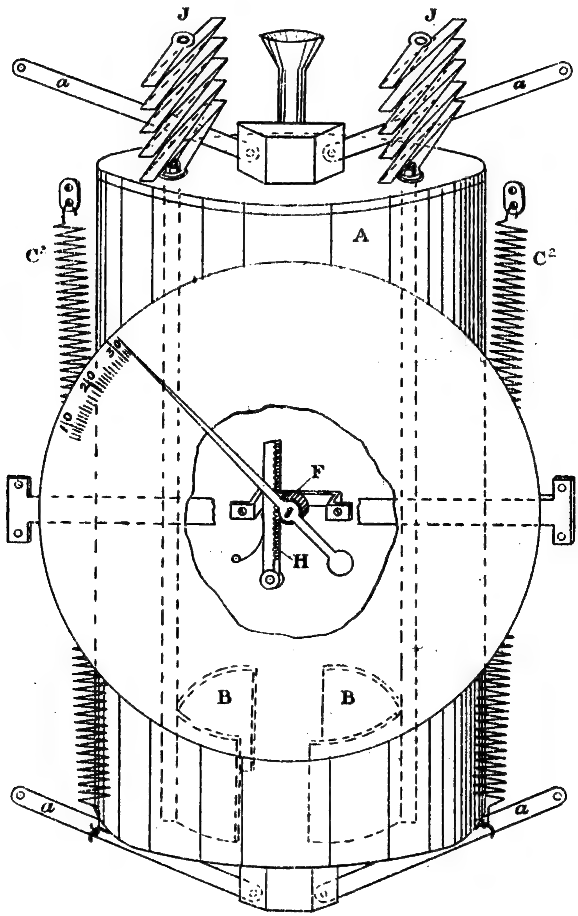


FIG. 1.

carry the current from the fixed terminals to the electrodes. The meter shown is intended for a current of 5 amperes, and the capacity of the vessel is such that current equivalent to 400 units at 200 volts may be registered before the meter requires refilling. The solid caustic soda to form the electrolyte is placed in the vessel A as soon as the meter is made; it is therefore only necessary to fill the meter with water when required for use. Since the electrolysis of a fixed weight

of water corresponds to 1 unit, the accuracy of the meter may be ascertained by placing upon the vessel a brass weight which is equivalent to the amount of water that would be electrolysed by, say, 100 units at the required voltage, and then seeing that the pointer moves over 100 divisions on the scale. Calibration of the meter in the first instance may be effected either by varying the strength of the springs

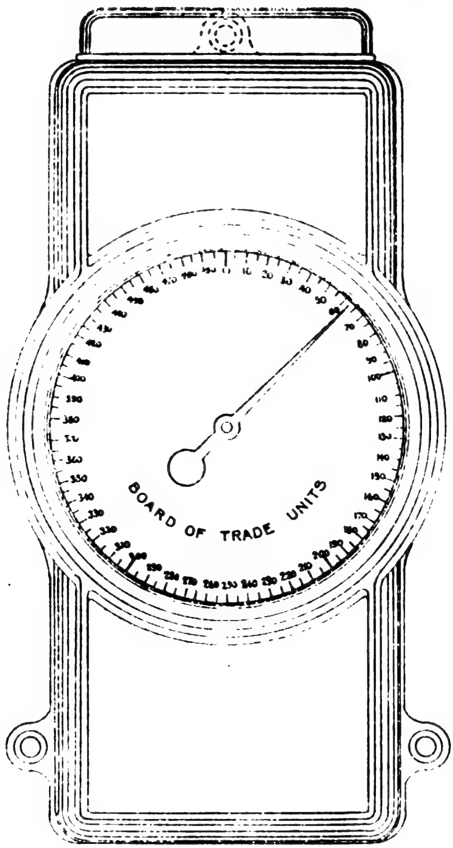


FIG. 1*a*.

or by using dials having fewer or more divisions in the circle, or by varying the number of teeth in the pinion. When a fairly large number of units has been registered, say 300, the reading is noted, and water again poured in until the hand stands at zero on the dial; registration can then go on as before. The actual weight of the vessel, when filled, is about 4½ lbs., and about 1½ lbs. of water may be removed by electrolysis before refilling becomes necessary. This would correspond to a total registration of 400 or 500 units. Fig. 1*a* shows the complete meter.

A meter such as the one just described is subject to the limitations and defects of its class, viz., relatively large fall of potential at all loads, considerable bulk, and the necessity of occasional refilling. On the other hand, it is accurate, simple, and easily handled. It also fulfils an object which was held in view when designing it, viz., the production of an electrolytic meter which contained no glassware and required no handling of chemicals. A number of meters of this kind have been made, and have worked satisfactorily as regards registration over a considerable period, and also the dial hands have remained perfectly stationary during a long period of rest, showing that no change in the electrolyte or springs took place.

It would obviously be fairly easy to include a ratchet-and-pawl arrangement in the counter of a spring balance meter, so that the registration went forward continuously instead of the hand being set back to zero at each refilling. One of the main objections to electrolytic meters could thus be eliminated.

A modified form of spring-balance meter has also been made, in which change in the specific gravity of an electrolyte (produced by electrolytic removal of water) is registered upon the dial through the medium of a submerged float.

Although it is hoped that the meter just described may be of practical utility, it is not of special theoretical interest. In the one that follows, however, an electrolytic process has been employed which the author believes to be new, and which he therefore hopes may be of scientific as well as practical interest.

The previous meter possessed the great practical advantages of a simple electrolytic process, and one for which the materials of electrolyte and electrodes may readily be obtained in a state of purity. An attempt was therefore made to enable such a meter to be shunted without at the same time introducing fatal complications. For a meter to be shunted, the first condition is that the current passing through it is exactly proportional to the difference of potential between its terminal electrodes; for this is the law governing the current passing through the metallic conductor constituting the shunt. Hitherto this condition has only been realised when the anode consisted of a metal which was dissolved while the same metal was deposited on the cathode, the metals employed in commercial meters being zinc, copper, and mercury. In order that a gas voltameter may conform to this rule it is necessary that gas should dissolve at one electrode and reappear at the other. A solid hydrogen anode cannot be made, but the equivalent of one may be obtained by using a mass of spongy platinum saturated with hydrogen; and if this anode is only partly immersed in the electrolyte and the remainder is exposed to an atmosphere of the hydrogen, sufficient gas will be absorbed and transfused to replace that which is dissolved away. Fig. 2 shows the arrangement in its simplest form. A and C are electrodes of platinum in dilute sulphuric acid contained in the vessel S. They are thickly coated with platinum black, and are only partly immersed. Above the electrodes is a sealed space, H, full of hydrogen gas. In such

an arrangement the smallest difference of potential (say $\frac{1}{100}$ of a volt) will cause a steady and continuous current to pass between the electrodes; hydrogen is evolved at the cathode, but no oxygen at the anode. Instead, the exposed surface of the anode absorbs hydrogen from the store above it, which combines with the oxygen as fast as the latter is produced. This arrangement is therefore comparable to a copper or silver voltameter in which the same metal is dissolved at the anode as is deposited at the cathode.

It will be seen that (within limits) it is possible to pass a current continually through an electrolytic vessel arranged as above without effecting any alteration in the volume or disposition of the electrolyte, the enclosed gas, or the electrodes; it may, in fact, be hermetically sealed up and used for an indefinite time.

If the electrolytic vessel thus sealed up is divided into two compartments, so that the gas evolved at the cathode does not immediately

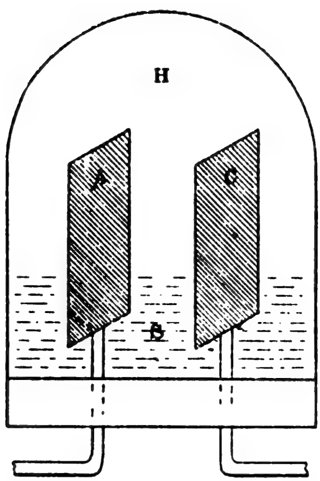


FIG. 2.

return to the general store, then the volume of the former may be used as a measure of the current passed, and being sealed up, its volume is not affected by changes of external pressure or temperature. After a certain amount of gas had been thus transferred from the store to the measuring tube, and the latter had become full, it would be necessary to return this gas to the store. This can be done by tilting the tube down, by which process it is re-filled with liquid and ready for a fresh start.

As explained above, the current passing through a meter of this type is proportional to the difference of potential between its electrodes, provided this current does not produce oxygen faster than the platinum anode can absorb hydrogen to combine with it

This condition is easily realised in practice. This property enables the meter to be shunted; a very small portion of the total current to be metered need be passed through it, and the amount of gas evolved during one or two years' service can be reduced to a quantity easily contained and read off in a graduated tube.

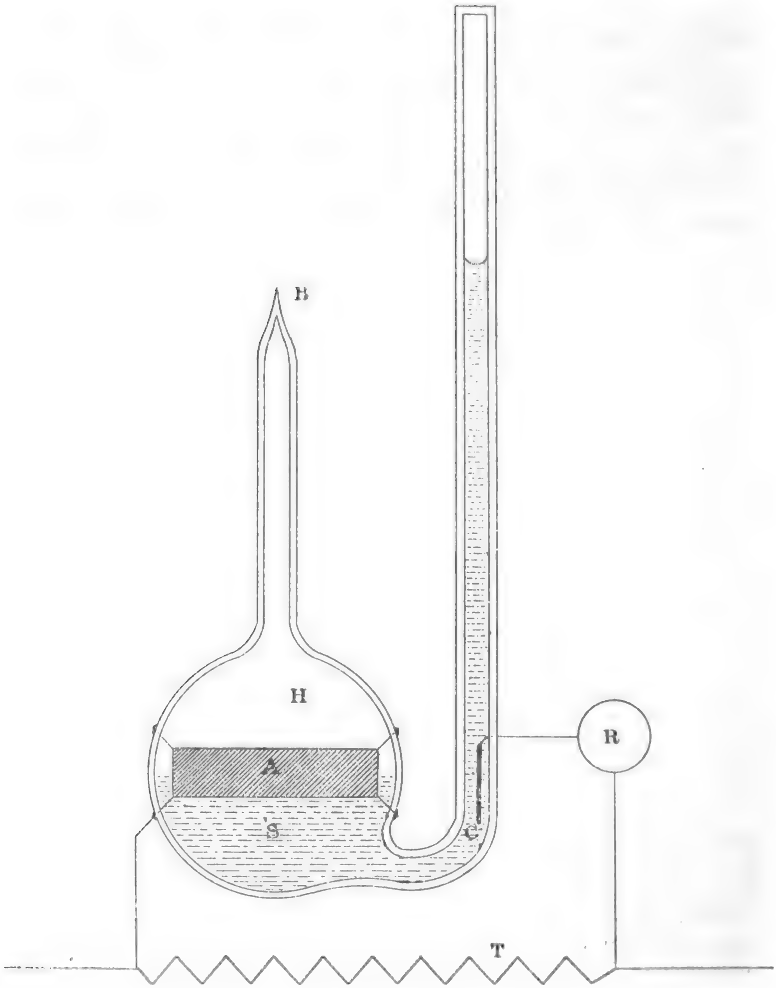


FIG. 3.

The volume of gas settled upon for this purpose is about $1\frac{1}{2}$ cubic inch, and is measured in a graduated glass tube $\frac{5}{16}$ in. internal diameter and 15 in. long. The scale is graduated into 300 divisions one millimetre apart—large enough to be read easily—and each division

corresponds to about 5 ampere-hours passing through the meter ; that is to say, one Board of Trade unit at 200 volts. To produce this volume of gas for the passage of 300 units, only one fifty-thousandth of the total current passes through the electrolyte, and an area of about one square inch of platinum anode is sufficient. The fall of pressure through the shunt of the meter is 1 volt at full load, so a resistance coil of 10,000 ohms is included in series with the electrolyte. This coil has the same temperature coefficient as the shunt, so that no temperature error exists from this cause. The added resistance coil being so large the resistance of the electrolyte is quite negligible.

Fig. 3 shows diagrammatically the essential parts of the meter in what is practically both its first and its final form. It consists of a vertical tube with bulb attached. C is the cathode—a platinum wire. A is the anode of sheet platinum, both coated with platinum black. S is the electrolyte, and H the store of hydrogen. R is the resistance coil, equal to about 10,000 ohms. T the shunt, which in a 5-ampere meter has a resistance of 0·2 ohm.

To start the meter, it is held with the tube nearly horizontal and below the bulb. All the gas then collects in the bulb, while the tube fills with electrolyte, which remains in it after it is restored to the vertical position for use. When a current is passed through the shunt a steady fine stream of gas bubbles rises from the cathode, gradually replacing the liquid in the tube.

Great care has been exercised, both in the experimental and in the complete meters, to use only pure materials. The hydrogen gas is produced from pure zinc and pure sulphuric acid, and is well washed before passing into the meters. Only pure acid and distilled water are used for the electrolyte, while the electrodes are treated with strong nitric acid and are well washed after being coated with the platinum black.

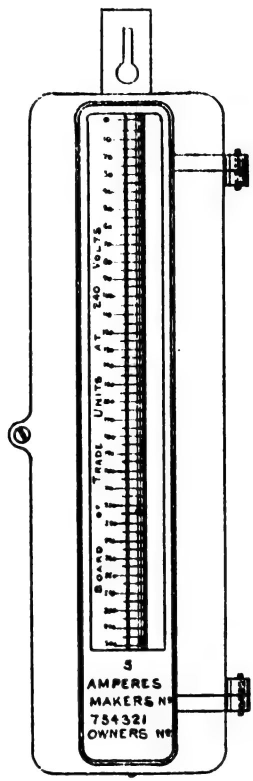


FIG. 4.

The process of filling is as follows : The short tube B (Fig. 3) is left open when the vessel is made. This tube is connected by indiarubber pipes to an air-pump, to a reservoir of hydrogen, and to a vessel containing dilute sulphuric acid. Cocks are arranged on each pipe. The air is first removed by the air-pump and hydrogen gas then admitted ; this, in turn, is exhausted out, and then the sulphuric acid is allowed to flow in to the proper level. Finally hydrogen gas is again admitted to

fill up the remaining vacuum ; the tube B is then sealed off in a blowpipe flame.

Experiments have been made with various electrolytes, but none give such good results as a 10 per cent. solution of sulphuric acid. Phosphoric acid is perhaps the next best. With solution of caustic soda and with hydrochloric acid there is a deficiency of gas produced, possibly owing to anode products getting across to the cathode ; while solution of sodic sulphate had a certain amount of back electromotive

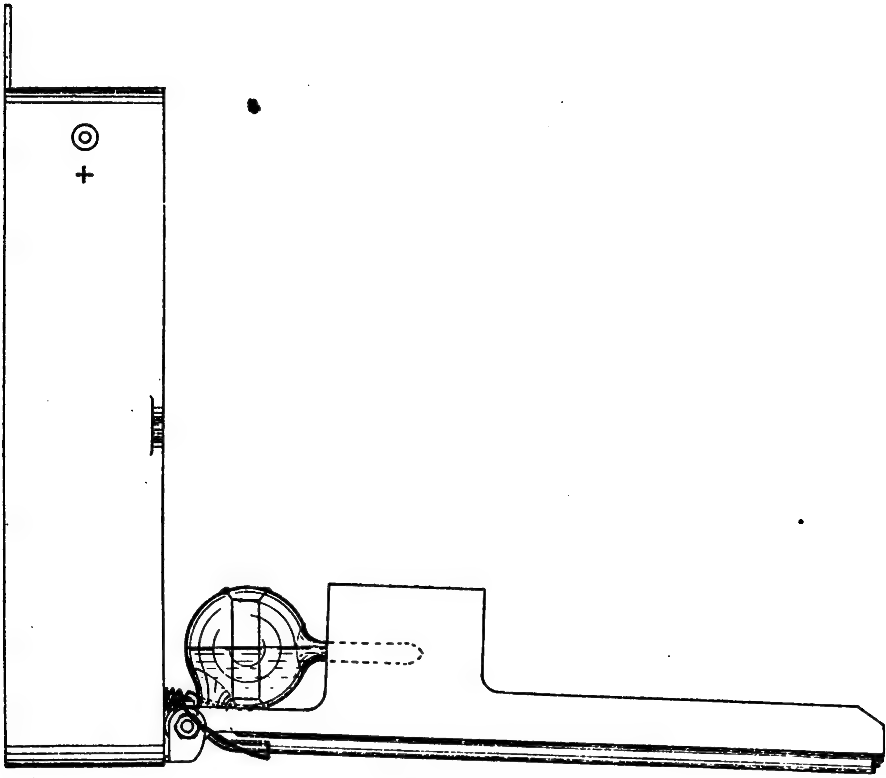


FIG. 5.

force which destroyed the accuracy with small currents. Anodes of palladium, and also cathodes both of palladium and gold, have been tried, but none appear to equal the platinum. It is remarkable that the material of the cathode is almost as important as the anode, only platinum well coated with platinum black being satisfactory. These facts seem to be connected with the phenomena of electrode excess potential, some account of which is given by Lehfeldt.* No very

* Dr. R. A. Lehfeldt, "*Electro-chemistry*," Part I., p. 176.

satisfactory explanation, however, is given of the cause of this, and perhaps there is scope for further research on the subject. Meters have been tried in which a porous partition was interposed between the anode and cathode. This was formed of a layer of fine white sand, which always collected in the bend of the tube when the meter was set upright. Such meters gave very good results, but so far have not proved themselves superior to the others.

In one case an anode was tried so arranged that one side of the platinum sheet composing it was exposed to the solution and the

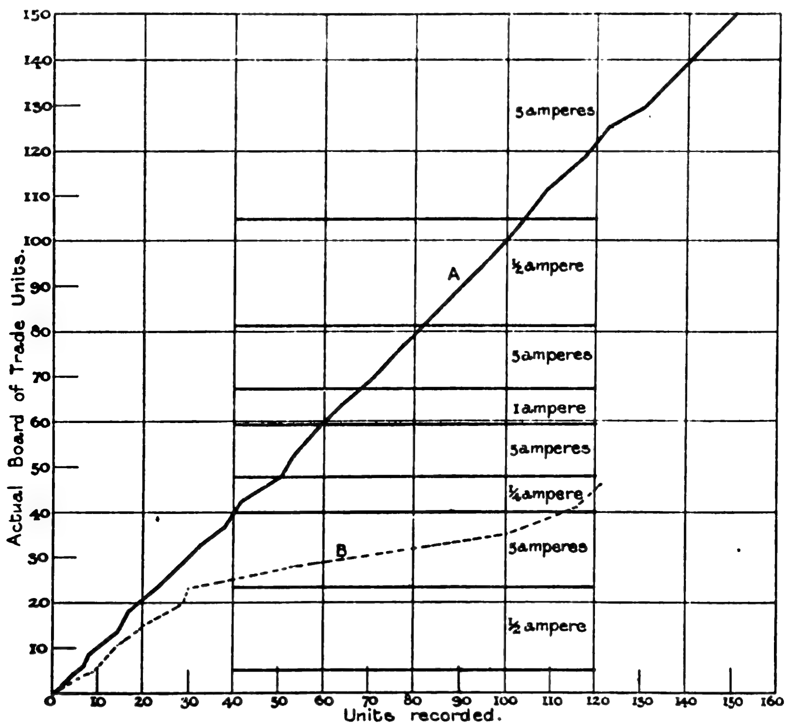


FIG. 6.

other side to the gas. In this case the hydrogen would have to pass actually through the sheet to get to the electrolyte, instead of creeping over the surface as in the other meters. The behaviour of this meter, however, proved that practically no gas did get through, and it was useless.

Some experiments have been made of passing alternate currents through these meters. It is well known that the ordinary gas voltameter will evolve gas with alternating currents, but the amount produced is dependent very largely upon the current density and the frequency of alteration. So far as the experiments have gone, the

same may be said to be true of the evolution of gas by alternating currents in this meter; and no novel feature in this respect has been noted.

Fig. 4 is a front view of a complete meter with the case closed, and Fig. 5 a side view of the same meter, having the tube tilted forward for resetting to zero. An incidental advantage of the design chosen is that almost the entire height of the meter is available for the scale, there being very little lost space either above or below.

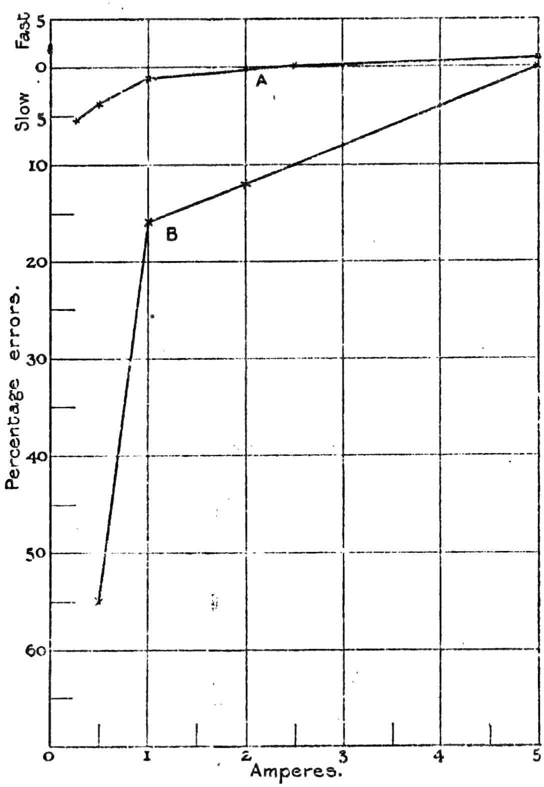


FIG. 7.

Fig. 6 shows curves taken over long runs, the electrolytic meters being tested against a motor meter, whose accuracy was checked for each load. The ordinates represent the actual ampere-hours passed through the meters and the abscissæ the amounts registered. The space is divided by horizontal lines showing the actual current passing. If the meters were perfect, each curve would be a straight line, and departure from this indicates that they are fast or slow for a particular strength of current. It will be seen that these meters are capable of giving very good results, as shown by Curve A. In Fig. 7 the

curve is drawn in a more usual manner, the ordinates being percentage errors and the abscissæ current; the data were, however, obtained from long time-tests, as the others. A curve of a bad meter (marked B) has been included with each for contrast, the difference being produced by the use of a polished cathode in the bad one.

Electrodes of platinum saturated with gas were employed in Grove's well known "gas battery," which was a kind of storage cell; similar electrodes have also been employed by recent experimenters for the purpose of measuring differences of potential between metals and electrolytes. Some account of these uses may be found in Arrhenius'* and in Lehfeldt's books on electro-chemistry, who give also references to original papers. So far as the author is aware, however, no use has hitherto been made of an electrolytic process involving the continuous absorption and solution of gas at one electrode and its evolution at the other. As the process, therefore, seems to be novel, it is hoped that uses may be found for it in other directions besides electricity meters.

The author desires to express his indebtedness to Messrs. R. Prosser and W. S. Sprague, of Chamberlain & Hookham, Limited, for their skill and patience in preparing apparatus and making experiments; and to Dr. Findlay for suggestions and advice.

DISCUSSION.

The CHAIRMAN (Professor R. Threlfall, F.R.S.): I consider Mr. Holden's discovery as being the first practical application, so far as my knowledge goes, of Helmholtz's chemical investigations on the electrolysis of water and allied subjects. (*Sitzungsberichte d. Akad. Wiss.*, Berlin, 1883 and 1887; and *Monatsbericht d. Berl. Akad.*, 1873, p. 584; *Pogg. Ann.*, 150, p. 483; Physical Society, London, "Physical Memoirs," vol. i. part 1.) The Chairman.

Mr. Holden's invention is of peculiar elegance, and I trust that it will work as well in practice as it appears to promise to do. But might it not be possible for the readings to be falsified if one limb were at a higher temperature than the other? For in this case the concentration of the hydrogen solution would be different in the two limbs, and, as a result of diffusion, there might be a continuous solution of the free gas on the colder, and a corresponding evolution on the warmer side. Is there not also a temperature coefficient of the resilience of the springs in the first form of meter described, which might lead to temperature error?

Mr. R. A. CHATTOCK: I consider that the advantages claimed for the first meter described over those in comparison with other electrolytic meters, of a similar type, are rather overestimated. The chief improvement seems to be that the materials used in the construction of the meter are strong and that no glass is employed. The fact that it is a simple matter to test the accuracy of the meter is also a Mr. Chattock.

* Svante Arrhenius. "*A Text-book of Electro-chemistry.*" Translated by Dr. J. McCrae.

Mr. Chattock.

distinct advantage. I assume that the drop of potential is about the same as in other meters of a similar type.

The second meter is a very interesting departure, and should, I think, prove successful in practical use, though time, of course, is required to demonstrate this. I should like to know if it is necessary to coat the electrodes with a certain definite quantity of platinum black, also whether any alteration in the condition of the electrodes is noticed after being in use for a considerable time, such as the peeling off of the platinum black, which is likely to affect the action of the meter. It would be interesting to know what would be the effect of a short-circuit on the meter and whether there would be any possibility of the glass tube bursting on account of the rapid evolution of gas.

Mr. Tilney.

Mr. M. J. E. TILNEY (*communicated*) : I am much interested in Mr. Holden's paper, not in any way as a manufacturer or from a scientific point of view, but merely as user. There are one or two points on which I should like to ask Mr. Holden if he can give us any information. First, as regards price. I imagine that this meter should be capable of being manufactured fairly cheaply, as I think it will be generally expected that unless a considerable economy from the cost point of view can be shown, electrolytic meters are not likely to be taken up. Then, dealing with the technical points of the meter, is the platinum black with which the electrodes are coated a permanent coating, or could it possibly deteriorate ? From the particulars given in Figs. 6 and 7, it would appear that the polishing of the cathode produces most disastrous results, particularly at about one-fifth full load. What is the effect of polishing the anode, and is there any fear that this platinum black will in course of time, say four years, become changed in its character, and thereby affect the accuracy of the meter? It would have been interesting if Mr. Holden had shown us on Figs. 6 and 7 the accuracy curves of a Chamberlain and Hookham meter of about the same size.

Another important point, which Mr. Holden does not mention at all, is how he proposes to deal with meters of larger capacity.

Also I should much like some information as to what effect overloads would have on this meter, and what its accuracy would be on overloads. This is a matter of some importance, as, I believe, most of the electrolytic meters at present on the market are not considered to be suitable for use on a circuit where they are likely to be considerably overloaded even for short periods. There is one other point which is not brought out in the paper, and that is as to the accuracy of the meter on very low currents; and if Mr. Holden could give us any information as to the accuracy which might be expected with the meter in use on a 240-volt circuit, with, say, one 8-c.p. lamp, I feel sure it would be of interest to supply engineers. One would be rather disposed to fear that, at the low figure represented by an 8-c.p. lamp on 240 volts, the error would be a good deal nearer 10 per cent. than 5 per cent. I know that this latter test is a very tedious one to take, but it is undoubtedly very important, in view of the endeavour which all supply engineers are making to supply small class houses where it

is not at all an infrequent occurrence to have only one lamp burning at a time. Mr. Tilney.

Mr. HOLDEN (*in reply*): The points raised by the Chairman and Mr. Chattock have had my attention. At first I thought that hydrogen might be transferred on account of difference of pressure in the vertical tube and bulb. I have also experimented with a lamp in close proximity to the bulb, causing considerable difference of temperature. There was no transfer of hydrogen due to either cause. I have also proved that there is no practical error in either meter due to change of temperature. There was a slight error in the early meters of the first type, due to the alteration in length of the springs, but by reducing the length of the springs I have entirely got rid of this error. Mr. Holden.

An advantage of the spring balance meter not referred to by Mr. Chattock is that a circular dial enables a scale to be used much longer than the total length of the meter. The platinum electrodes are treated with a good thick coat of platinum black, but of no definite amount. So long as the platinum itself is entirely covered, the amount of platinum black does not affect the accuracy of the meter. I have had meters running continuously for many months without showing any falling off in accuracy. As regards a short-circuit, the meters which I am exhibiting to the meeting are running with a current through the electrolyte of three hundred times the normal value. I am running them with the resistance short-circuited in order that you may see the evolution of gas, which under ordinary circumstances is not easily detected. It is evident that no harm will be done by a short-circuit.

Some of the questions asked by Mr. Tilney have already been dealt with in replying to other speakers. I agree with him that the employment of electrolytic meters is largely a matter of price. The meters exhibited were designed with a view to low cost of production; but the question of selling price is one for the manufacturers, and does not come within the scope of the paper. The stability of the platinum black can only be determined by experiment. Anodes in continuous use for six to eight months show no signs of deterioration; this may be taken perhaps as equivalent to two or three years' ordinary use. The question of larger meters has not been considered, because it is thought that for such meters the electrolytic type cannot usefully compete with the motor meter. Finally, in reference to Mr. Chattock's remarks and Mr. Tilney's request for comparative curves, I would point out that I have throughout felt it desirable to abstain from drawing any comparison between my meters and those of other inventors.

LEEDS LOCAL SECTION.

SECONDARY CELLS: THEIR DETERIORATION AND THE CAUSES.

By G. D. ASPINALL PARR, Member.

(*Paper read at Meeting of Section, December* 13, 1905.)

Comparatively little or no literature of a definite nature exists in connection with the effects of impurities, either in the plates themselves or the electrolyte in which they are immersed, on the E.M.F., capacity, and life of secondary cells. That certain impurities are injurious to the action of the lead-sulphuric acid cell is fully realised by every manufacturer of these cells. In fact all agree that there must not be more than a given percentage of certain impurities, and no trace of others, present, but the exact maximum amount of each admissible is indefinite and a matter of conjecture. Doubtless want of more exact data in this direction is due to the costly, lengthy, and extremely laborious nature of the research entailed by the quantitative determination necessary to elucidate this matter. That such should be a reason is surprising, in view of the occasional dismal failures of storage batteries which are reported, as well as of the heavy capital sums at stake in connection with them. Ten years ago the capital involved in this country in connection with the manufacture of storage cells was about £426,000, now it is about £987,000, while the capital expended in the purchase of this class of appliance is much greater now, in proportion to capital, than it was ten years ago. The reason for such rapid strides lies in the many uses to which secondary cells are now being put, as, for example, in electric lighting and power stations, private installations, road traction, and portable purposes, telegraphy, telephony, and many others. It is common knowledge that the prime cost of a storage battery, having a given kilowatt output for a given time, is about the same as for a steam generator and boiler of the same output. The useful life of the battery will be less than that of the steam plant, while the energy efficiency of the former will range from 60 per cent. to 80 per cent., with an average, under commercial conditions, of about 70 per cent. Notwithstanding these facts, a considerable saving in running cost, as well as greater convenience and constancy of pressure, is effected in many systems of supply of electrical

energy (even when alternating), by the installation of a suitable storage battery.

Naturally the points which interest and affect the purchaser of a battery most are (1) the prime cost, (2) the maintenance of its capacity, (3) its useful life. Both the efficiency and capacity of secondary cells gradually diminish with the time of use, the falling off being due to (*a*) natural causes, (*b*) unnatural causes, which embrace the effects of *ill-treatment* and *impurities* respectively. Under heading (*a*) we have loss of active material and loss of porosity, and under (*b*) we have, firstly, the ill effects of excessive charge and discharge rates, short-circuits, and those due to allowing cells to rest in a discharged condition and never fully charging them up; secondly, the ill effects of impurities in the cell, which is the main subject of the present paper. If we assume that a secondary cell is made from pure materials and is installed ready for use with no impurities in either electrolyte or plates, then its natural life will depend on its construction and on the treatment to which it is subjected. If, however, impurities are present, then no matter how carefully it was made and is used, the longevity will be affected. Impurities may be introduced through the medium of the plates, or through the electrolyte, or by reason of the salts formed by corrosion of the cell connections dropping into the solution. Plates of the Planté, or non-pasted type, are given porosity in the course of manufacture by treatment in some oxidising or so-called pickling solution, containing nitrogen compounds—for example, nitric acid, ammonia, nitrates of sodium, potassium, ammonium, and ammonium sulphate. Manufacturers of such plates, however, take precautions to eliminate all traces of these compounds before the plates leave the works, and this is not difficult to do. Assuming that this is done, it remains for us to consider the main source of trouble, namely, the impurities liable to be introduced through the medium of the electrolyte. These may be present either in the sulphuric acid (the same grade from the same maker often varying greatly in purity), or in the water with which it is mixed. According to Dr. G. Lunge, the greatest living authority on sulphuric acid, the concentrated acid of commerce may contain :—

Sodium sulphate (135 parts in a million).
Potassium sulphate (more rarely).
Calcium sulphate (58 parts in a million).
Ferrous sulphate (291 parts in a million).
Lead sulphate (520 parts in impure and 172 parts per million in pure acid).
Aluminium sulphate.
Sulphate of ammonia (very largely).
Copper, zinc, and other metals (rarely).
Selenium.
Arsenic (500 to 1,420 parts per million).
Hydrochloric acid.
Hydrofluoric acid.

Sulphurous acid.
Antimony (80 parts per million).
Arsenious acid (1,420 parts in impure and 31 parts per million in pure acid).
Compounds of nitrogen (always present).

Ammonia has been found in acid to the extent of 6,700 parts per million, but it is often present in 3·6 parts per million and is the most common impurity. Sulphuric acid is prepared either from sulphur by heating it in a current of air to form sulphur dioxide or from sulphide of iron (iron pyrites). The former method gives what is known commercially as "brimstone" acid, the latter method an acid which (unless very carefully purified) contains traces of iron, arsenic, and other metals. It is therefore safest to use "brimstone" (which is usually free from arsenic) acid for storage battery purposes, unless careful analysis is resorted to. Both kinds of acid are liable to contain traces of nitrogen compounds. In general there is ample evidence of much impure acid being used for storage cell purposes. According to Dr. R. A. Smith, in his standard work "Air and Rain," 1872, rain water has been known to contain the following impurities to the maximum extents given, namely :—

Hydrochloric acid (chlorides) (560 parts per million), greatest at the sea coast.
Sulphates (1,226 in a million), greatest in large cities.
Ammonia (London, 32 parts per million; Glasgow, 9 per million).
Albumenoid ammonia (London, 1·08 parts in a million; Liverpool, 0·66 in a million).
Nitric acid (London, 25 parts per million).
Nitrates.
Other substances found in rain are organic substances, soda, potash, magnesia, alumina, carbonic acid, lime, oxide of iron, and manganese.

Over 100 parts per million of foreign matter have been found in rain.

Water from town mains may contain sodium chloride, sulphuretted hydrogen, sulphates of ammonium and potassium, magnesium, calcium, the last two making the water hard but drinkable. Most impurities would be alternately oxidised and reduced with succeeding charges and discharges, and would thus help to discharge the cell irrespective of whether it is sending a current externally or not. It is well known that cells standing idle slowly discharge, the density of the acid becoming weaker; this loss of charge in a good cell amounts to from 1 to 2 per cent. of its total capacity per day, but may amount to from 40 to 50 per cent. if the cell contains impurities. Impurities in the form of metals which are more electro-negative than lead are deposited on the latter, forming with it a short-circuited local element, which causes lead sulphate to form in the active material of the negative plate and

hydrogen to be evolved. Metals that behave in this way are iron, silver, nickel, copper, etc., the loss of charge being due principally to (1) the chemical action of sulphuric acid on the spongy lead; (2) the increase in density of the electrolyte, the sulphating of the negative increasing rapidly with the density; (3) the electro-chemical action of the couple formed by the spongy lead of the active material of the negative and the lead of the support, especially when this contains impurities such as antimony (under 1 per cent.); iron; and copper from corroded connections.

This *local action* is about three times greater at a sp. gr. of 1,300 than at 1,170 for a temperature of 15° C. L. Jumau finds that high density suits the positive much better than it does the negative plate and therefore that the best result and highest capacity will be obtained by making the total area of the negative plates greater than that of the positives. On the other hand, the more electro-positive metals, such as tin, zinc, mercury, etc., can do no harm in the solution. Manganese salts, often met with as an impurity in litharge, are to be avoided, owing to the formation of permanganic acid at the positive plate, and to the consequent setting free of the oxygen of the active material of this plate. From these remarks it would appear that considerable risk is run by the use of either rain water or town water, and hence the only other option is to use pure distilled water. This is unfortunate in one way on account of the cost, but when carefully considered, it is trifling compared with the cost of a new battery, which the use of impure water might entail. The practice which some central station engineers adopt of using the condensed steam from the boilers is dangerous, because boiler water, in addition to its natural impurities, often contains some special alkaline softening fluid. Some of the more volatile impurities in this may, therefore, be carried over with the steam and condense with it, giving possibly a more impure water than that derived from rain or town supply. Another equally dangerous custom with some engineers is to add from 1 to 2 oz. of ammonium sulphate, sodium sulphate, or sodium carbonate per gallon of the electrolyte, with the object of improving the condition of the cells. This practice, while giving a rich colour to the plates, in time acts detrimentally on them, diminishing both capacity and efficiency. Accepting the limitations put by battery makers on the amount of impurities allowable, it would seem that the electrolyte should be free from arsenic, nitrogen compounds, sulphuretted hydrogen, sulphurous acid, and organic matter, and that it should contain only mere traces of hydrochloric acid and iron. Mr. R. W. Vicarey has recently found that from 10 to 0·1 per cent. of ammonia added to the solution decreased the capacity immediately by some 20 to 31 per cent., thus showing the deleterious effect of nitrogen compounds. The ammonia has a strong affinity for water and turns to nitric acid on the passage of a current.

I have recently commenced a series of tests with a view to determining the maximum amount of any given impurity which may be present in a secondary cell without seriously affecting its capacity and efficiency. The tests, which will continue for many months, and are at

the present time, therefore, obviously incomplete, are being operated on 14 exactly similar cells. Each cell has one positive and two negative plates, all of the Planté type, and 5 ins. × 5 ins. × ¼ in. in size, contained in a glass box 6¾ ins. × 5¼ ins. × 2 ins. inside. The normal charging rate is listed as 2 amperes, and the discharge rate as 1·5 amperes for ten hours (normal capacity 15 ampere-hours); 2 amperes for six hours and 3·5 amperes for three hours, with an electrolyte of sp. gr.=1,205. The manufacturers were asked to make them all under the same conditions, and particularly to insure the elimination of all nitrogen compounds, both of which requests were carefully attended to. Scrupulous care and cleanliness was observed in mixing the various electrolytes. The sulphuric acid used was specially pure for analysis, but was, together with the distilled water used, analysed for possible and probable impurities, none, however, being found. For help in this work and for many valuable suggestions I am greatly indebted to Dr. H. M. Dawson, of the University, Leeds. Eleven of the commonest impurities in sulphuric acid and in water have been chosen, and in amounts at least equal to the maximum which has ever been found in any ordinary water and ordinary purified *commercial* acid. One cell contained pure electrolyte and three others contained different percentages of sulphurous acid. The following table shows the impurities used and their proportion per million parts of the solution :—

Cell No.	Impurity.	Parts per Million.
1	Arsenic	225
2	Ammonia	27·5
3	Antimony	33
4	Copper	40
5	Zinc	40
6	Sodium	45
7	Iron	115
8	Sulphurous acid (SO_2)	6
9	Calcium	83
10	Nitric acid	25
11	Hydrochloric acid	50
12	None	—
13	Sulphurous acid (SO_2)	0·6
14	Sulphurous acid (SO_2)	2

Twenty-two charges, all at 2 amperes, and 22 discharges, also all at 2 amperes, have so far been taken in succession day and night, and the following curves indicate the effects produced on the various cells. In the case of the charge curves it will be seen that sulphurous acid (Cells Nos. 8 and 13) greatly affects the rate of rise of terminal PD, distorts the ordinary form of curve, and diminishes the capacity, and further, that apart from Nos. 12 and 14, no very unusual results are noticeable.

The discharge curves, 1, 2, 4, and 13, show a much better result

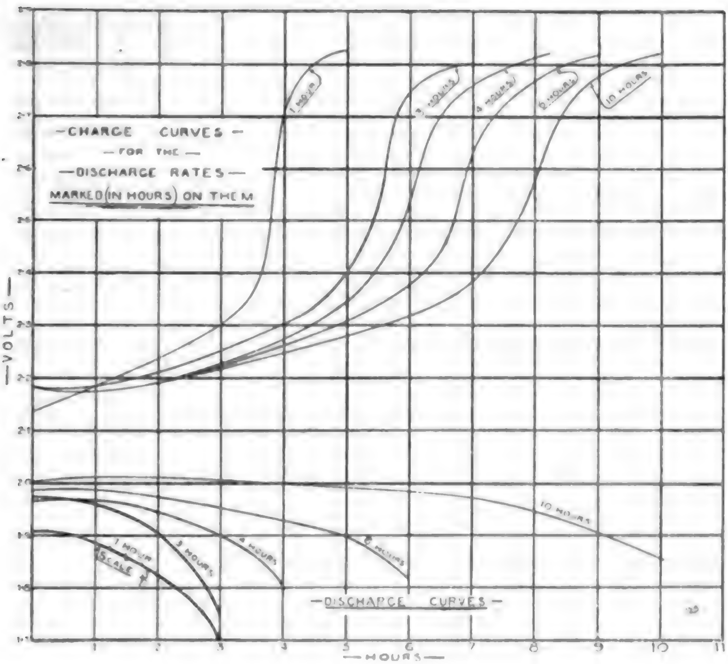

—CHARGE CURVES —
— FOR THE —
—DISCHARGE RATES—
MARKED (IN HOURS) ON THEM
—DISCHARGE CURVES—
—VOLTS—
—HOURS—
1 HOUR
3 HOURS
4 HOURS
6 HOURS
10 HOURS
1 HOUR SCALE

FIG. 1.

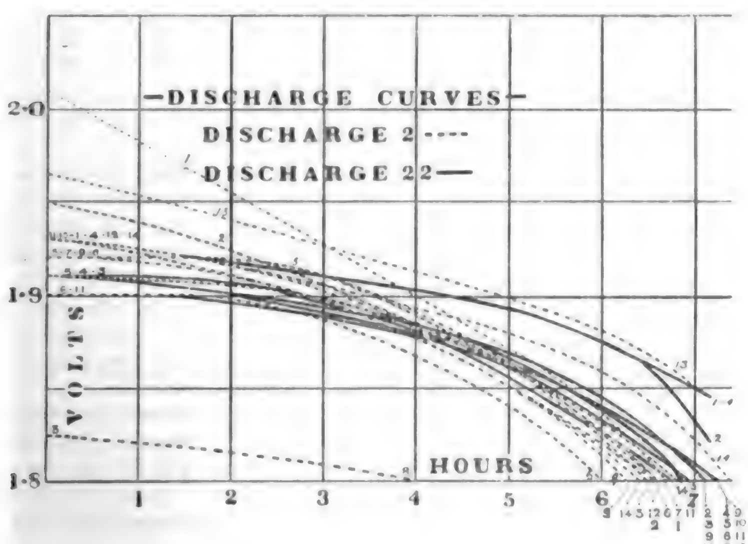

—DISCHARGE CURVES—
DISCHARGE 2 ----
DISCHARGE 22—
VOLTS
HOURS
2·0
1·9
1·8
1
2
3
4
5
6
7

FIG. 2.

than the rest of them, the mean voltage and time of discharge being greater in these, but as seen, they are falling off with the number of discharges. No. 8 shows very clearly the deleterious effect of sulphurous acid, the capacity of this cell being almost annihilated after five discharges. The comparatively low voltage at the commencement of the discharge is due to the higher current rate used—six hours instead of the normal of ten hours. With the exception of No. 8 cell, the specific gravities of all the cells were about the same at corresponding points of the charge and discharge; that of No. 8 was, however, very low for both. Doubtless the effects will become more marked as the tests proceed, and I much regret the incomplete nature of the results at this stage.

I now give some curves showing the results of a lengthy series of tests which I made some time ago for a storage battery company on several large 9-plate storage cells having 4 Planté positives and 5 pasted negatives. The results are interesting and instructive as showing the effects of a variation in the charge and discharge rates on the capacity and efficiency of the cells, which I have given in the accompanying table:—

Discharge.			Ampere-hours.		Watt-hours.		Efficiency.	
Rate in Hours.	Limit in Volts.	Current in Amps.	Input.	Output.	Input.	Output.	(Amp.-hour) Quantity.	(Watt-hour) Energy.
10	1·85	29	318	290	764	574	91·2	75·1
6	1·80	42·5	288	255	730	449	88·5	67·7
4	1·80*	50	224	200	517	385	89·3	74·5
3	1·75	70	256	220	630	402	85·9	63·8
1	1·70	134	168	134	414	247	80·0	59·7

* This should have been about 1·77 volts, which accounts for the efficiencies at this rate being disproportionate with the rest.

The normal charging current = 32 amperes, discharging current = 29 amperes at the ten-hour rate, and 134 amperes at the one-hour rate. Fig. 3 shows very clearly that the higher the discharge rate is, the shorter the time of charging and the smaller the output. Fig. 4 shows that within the current limits taken the charging rate has but little or no effect on the output of the cell at the particular discharging rate taken.

All the curves of Figs. 3 and 4 are the means of the last two or three out of some ten charges and discharges at the particular rate shown. The cells had therefore arrived at a normal state for each rate.

In conclusion I wish to express my great indebtedness to Messrs. G. Whitaker, F. O. Foulds, B. W. Elliott, W. G. Maddison, C. T. Pearce, and R. J. Watmuff, six of my third-year students, for the very earnest and painstaking manner in which they have conducted these laborious tests thus far, day and night without intermission, and also to the two first-named gentlemen for plotting the curves shown in Figs. 1 and 2.

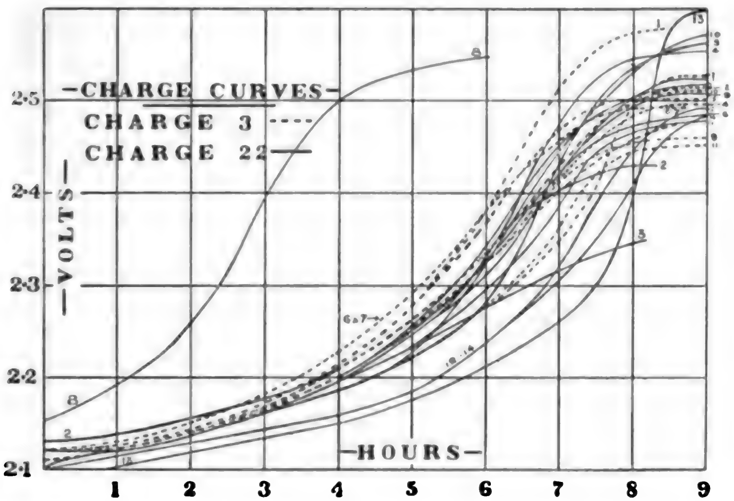

—CHARGE CURVES—
CHARGE 3
CHARGE 22
—VOLTS—
—HOURS—
2·1
2·2
2·3
2·4
2·5
1
2
3
4
5
6
7
8
9

FIG 3.

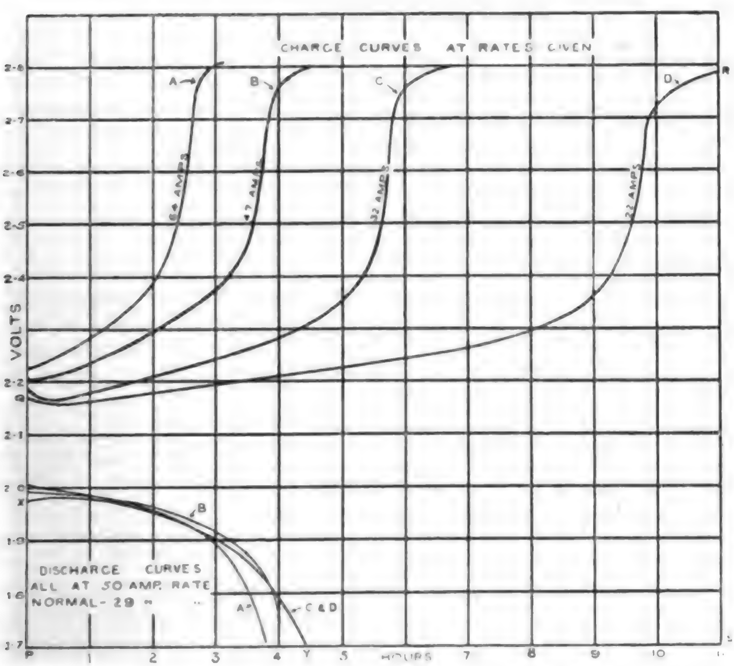

CHARGE CURVES AT RATES GIVEN
64 AMPS
47 AMPS
32 AMPS
22 AMPS
VOLTS
DISCHARGE CURVES
ALL AT 50 AMP RATE
NORMAL - 29 " "
HOURS

FIG. 4.

DISCUSSION.

Mr. Emmott.

Mr. W. EMMOTT: The increase in capital outlay on batteries during ten years is gratifying; at the same time it might have been expected to be considerably higher, taking the increase in other plant during the same time; this is no doubt caused by the want of confidence in storage batteries amongst central station men in particular, up to a comparatively recent date, due in the majority of cases, not to the battery, but to those in charge of it, who appear to have the impression that any kind of treatment is good enough. Batteries are now, however, receiving more reasonable attention, and no doubt the next ten years will see a vastly increased application compared with the past. If weekly readings of the specific gravity and E.M.F. of the cells are taken, and intelligently made use of in bringing up a weak cell by means of a milking booster or a couple of portable cells always kept charged, no trouble will arise. The leading manufacturers will maintain their batteries at anything from 5 to 6½ per cent., subject to reasonable attention, and where facilities are at hand this can be done at even less by one's own staff. Manufacturers take care to get at least 99·9 per cent. pure lead, and this metal being one of the easiest to purify, there is no difficulty in this, the 0·1 per cent. of impurity being distributed to such an extent as to be considered infinitesimal. Regarding impurities due to formation, as in a well-arranged factory this would be all eliminated before making up the battery, we can turn to the electrolyte as the place where to expect impurities. In the past I have gone to the trouble of using distilled water, but as far as the West Riding of Yorkshire is concerned I have found town's water good enough for all practical purposes, and this is borne out both by experience and analysis; therefore the matter is reduced mainly to the question of the quality of the H_2SO_4, and there are now three or four makers in Yorkshire who thoroughly understand the requirements of storage battery work, and there is no difficulty in getting a pure acid. A fault which was often practised in the past was, in the case of the battery getting down, to add acid, probably from a carboy which had been exposed to the atmosphere for some time, and in addition to absorbing moisture from the atmosphere, which would do no harm, had taken impurities. This is to be condemned; the proper remedy to apply being to get the battery back to its normal state by one or more long charges and reasonable discharges. The final results of Mr. Parr's researches will be interesting, and especially the result of the combination of more than one impurity in each of the cells.

Mr. Woodhouse.

Mr. W. B. WOODHOUSE: With regard to the efficiencies which the author mentions, I may say that in practical work I have never obtained such high figures.

Mr. Churton.

Mr. T. H. CHURTON: It would be very interesting to know the results of the experiments which the author is conducting. Unfortunately, however, the conditions are not such as would usually obtain in practice, the impurities not being met with singly but in

combination; and it does not follow, of course, that the effect of the various impurities, when in combination, will be the same as that due to each impurity by itself. It may be, indeed, that some impurities have a tendency to counteract the effect of others. For this reason I think it would be of practical interest if various samples of water, containing various impurities, were used, together with samples of acid containing impurities usually met with, and the results of these noted. Perhaps the author may be able to make a few such tests in connection with the present series of experiments. I would be glad to hear the author's views with regard to the probable use of accumulators for automobiles. One of the specimen plates shown, the "Headland," appears to me to combine considerable mechanical strength with lightness, and should, apparently, have a good capacity factor. Can the author give any information in this connection with regard to the Edison cell? Mr. Churton.

Mr. T. ROLES: As regards efficiencies I have found that the batteries that I have most recently had experience with can be worked to a daily ampere-hour efficiency of 95 per cent. I first started working to this efficiency with a Hart battery. Previously it had been my practice to give batteries about 10 per cent. overcharge, but the Hart Battery Company were very precise on the point of not overcharging, and they requested us rather to undercharge them than to overcharge, because doing the latter had the effect of softening the plates. We worked to about 95 per cent. efficiency daily, and at the end of every week we gassed the cells up, and for practically three years, during which my experience extended, this method acted admirably. The watt-hour efficiency, as far as I can remember, was between 75 and 80 per cent. week after week. We have a Hart battery now at Bradford, which we are charging in the same way, and at the end of the week the ampere-hour efficiency is about 94 per cent. As regards this battery I cannot give any details as to the watt-hour efficiency, as it is on a traction circuit with a reversible booster. The charge and discharge are taking place almost momentarily, and although we can take the ampere-hours by means of meters, we have no watt-hour meters in circuit. Mr. Roles.

We have another battery of about 2,400 ampere-hours' capacity at 200 amperes' discharge rate, and about 500 amperes for three hours, on our lighting system, and we are charging that in the same way, and I have here a series of readings showing that the average ampere-hour efficiency of the positive side during the month of November was 94·5 per cent. The ampere-hour efficiency of the negative battery for November was 94·3 per cent. The watt-hour efficiency of the positive battery was 79·9 per cent. for the month; for some reason the efficiency of the negative battery was shown as being higher, 83 per cent., which was probably due to inaccuracy of the voltmeters. I found that to work to 80 per cent. watt-hour efficiency is quite a regular thing with this battery.

I am unable to give the rate of discharge from the battery because I have not the figures by me, and the rate of discharge varies

Mr. Roles. so much according to circumstances, but we generally discharge fairly heavily at peak times. In this case, the discharge of the negative battery during the month was more than double the amount of the positive, because it was taking the out-of-balance current to a large extent, but with the time at my disposal since reading Mr. Parr's paper I have not been able to do anything more than gather together the information given. I have also been unable to satisfy myself regarding the differences in the watt-hour efficiencies of the positive and negative batteries, but I can guarantee the ampere-hour efficiencies, because they were being worked to very strictly. Since November the average ampere-hour efficiency of the Sunbridge Road Traction Battery, according to the meters (which have been recently calibrated) is 95 per cent.; at times the efficiency has gone up to 97·9 per cent., and in some cases down to 93·6 per cent. In perusing the paper I was greatly impressed with the number of impurities which might be in the acid and their effect, and we are just now having some correspondence with a battery company on the same matter. In this connection I must state that I totally disagree that it is advisable to enter into a maintenance contract with a battery company for a number of years.

(The CHAIRMAN: May I ask if you have had any experience with E.P.S. batteries and, if so, what it has been?)

I had trouble when at Aberdeen with E.P.S. batteries. The plates were arranged in nests, two nests in each cell, and after a year or two the pellets fell out of the grids of the negatives, and the positives softened. Buckling occurred in many of the nests, the plates being removed time after time, straightened out between boards, and replaced. On condition that the Corporation would afterwards take up a maintenance agreement with the company at a fixed rate per annum, the company offered to replace all bad plates and put the battery into thorough working order. They did not anticipate having to replace many plates, but as a matter of fact they had to replace practically the whole of them. Even then the discharge guaranteed could not be obtained. It was decided to increase the storage capacity at the works, and the E.P.S. Co. offered to replace the old type battery plates with a new type plate having a celluloid envelope, and to put in another battery of equal size if their tender was accepted. The Corporation agreed, and the new batteries were installed. I have had no experience with these, but I believe they were a failure owing to the rapid deterioration of the celluloid. The E.P.S. battery at Bradford, which is of their "P" type, with 43 plates per cell, each burnt on to a bus-bar arranged between two cells, has had some very heavy work, and I must say that it is doing very well. It has been in commission for five years, and although its capacity has dropped very considerably, the replacement of about 75 per cent. of the negatives recently has again brought it up to the specified rates. A very careful watch is being kept on the battery, and at present its behaviour is very satisfactory. The original positives are still in use. One of the most satisfactory batteries with which I have had experience was the Crompton-Howell

battery of twelve years ago. There was a rumour that the inventor had died, and that the secret of making the original plates died with him, as later batteries of this make were not so satisfactory. With this battery, as in nearly all others in my experience, although the plates were sent separately, the cells built up on the job, and the acid taken from the same batch of carboys, two or three particular cells would always give trouble week after week, while the remainder of the cells in the battery would be satisfactory. With this in mind, I would like to ask Professor Parr whether he has taken a series of tests of all the cells together, discharging them all in series, and comparing the capacity of one cell against that of another when each is used under exactly similar conditions. Otherwise, would it not be better to place three cells under exactly similar tests, as although every precaution is taken by the makers, cells often vary very much one from another with regard to their capacities? I may mention that in Bradford we have found considerable difficulty in procuring pure distilled water and are still using tap water; the quantity of distilled water which we would require would be sixty gallons per week. Our cells need one pint of water each per week to make them up. The Sunbridge Road Battery is less than half the capacity of that at Bolton Road, but it takes the same amount of water. I put that down to the fact that at the former works the cells are, for long periods each day, kept at the gassing point, owing to their being used in connection with a reversible booster on a traction circuit. The kilowatt output of the batteries at Bradford at their three-hour rating is 270 lighting battery, and 130 traction battery, a total of 400 k.w., which is equal to 4·6 per cent. of the capacity of the generators installed. Mr. Roles.

The CHAIRMAN (Mr. A. B. Mountain): We must thank the author very much indeed for bringing forward the results of his interesting researches. It must be a very difficult matter to write a paper when half way through experiments, and we shall all look forward with pleasure and interest to the final results of his experiments, which will, I hope, be communicated to a future meeting. I hope the author will bear Mr. Churton's point in mind, and deal with some known samples of town water, for it does seem to me that impurities mixed together would have quite a different effect to what they would have singly. I would like to ask Mr. Roles what proportion the batteries bear to the total generating plant at Bradford. My opinion is that batteries are of little use for real hard work, but they are undoubtedly of great use for maintaining a constant pressure of supply. The Chairman.

Mr. PARR (*in reply*): Mr. Emmott said that he had taken no particular care with regard to impurities in the electrolyte used by him in secondary cells. His experience in working results has been a happy one, but mine has been otherwise in one or two cases. I had a cell sent to me about three years ago by a storage battery company, and I used some ready-mixed acid supplied specially by an acid manufacturer for this cell, following the directions closely. Mr. Parr.

Mr. Parr. When I came to use the cell I could scarcely get anything out of it. Being much troubled about the result, I wrote to the makers of the cell on the matter, and eventually their representative called and suggested that we should make a test together, and this we did, with the same results. He wired to his firm the same day for a new cell, which came duly to hand. This time I took the precaution to use pure acid and distilled water mixed by myself, with the result that this new cell behaved quite normally, showing that there was evidently something in the acid in the first case, as I was assured that the two cells were made under similar conditions. I can only put it down to the acid. I have had one or two other instances in which the capacity of a certain battery did not come up to the maker's standard, due probably to impure electrolyte. With regard to refills, if ordinary town water is used, it is important to consider the amount of any impurity that might accrue in the course of a year. Obviously this might be very considerable where perhaps something like 15 or 20 gallons of water are added per week, so that the use of distilled water for refills seems to be essential unless it be ascertained that the town water is sufficiently free from impurities. With regard to the insertion of acid, it is usually the water of the electrolyte that disappears, so that it is very seldom necessary to add acid to the cell. I would mention that it is extremely important to keep the specific gravity of the electrolyte always the same, for the same temperature, in a fully charged cell. Probably only a few engineers realise the effect of the specific gravity of the acid on the general behaviour of the cell. For instance, the local action going on in the cell increases very much indeed with the specific gravity of the solution. This action is two or three times greater at a specific gravity of 1,300 than at 1,170 for a temperature of 15° C., and means deterioration and loss of capacity. My experience has been, in some cases, that the specific gravity has actually increased to an altogether dangerous extent, with a resulting loss of capacity. The specific gravity of the solution ought to be attended to, and kept more or less uniform. With regard to the remarks of Mr. Churton, there certainly is a good deal to be said as to the method of testing with the impurities one at a time and several at a time, but of course there are certain combinations of elements which would undoubtedly act on the cell in exactly the same way as the separate elements. For instance, magnesium and calcium will act in the same way in the cell, and consequently only one of them need be tried. Certainly the effect of a combination of impurities is an important one, and I hope at a later date to be able to give some results in this direction. With regard to the question of cells for automobiles, I might say that the "Headland" cell referred to has been used for many years in electric vehicles. It is coming rapidly to the front, and is a very good one indeed. You can see by the construction of the grid that there is practically no dead weight to be carried about in the form of a lead backbone, whilst at the same time there is plenty of conductivity in the metal of the grid for th

current to be delivered quite easily. The construction, however, is rather peculiar. In the case of a complete plate spaces are left between the bars, and the action not only goes on at the surface of the plate, but also at the two remaining sides of each of the individual bars. With this arrangement the capacity is very nearly double that of a plain lead plate, and consequently the output per lb. of cell is very large for this type of cell. I have several cells in use at the University, and apparently they will stand rough treatment without damage. Some few years ago I discharged a 3-ampere cell at ten times its normal rate for just over half an hour down to the usual limit of terminal potential. I subsequently short-circuited it through an ammeter, and it gave 54 amperes for one minute and a half, with the usual fall of terminal PD, and there was no buckling or falling away of paste. Regarding the Edison cell, this is in use in the States, but not, to my knowledge, in this country at the present time. The makers have made several improvements recently. They found that there was a considerable loss of capacity in connection with the positive plates, and they have overcome this trouble by doubling the number of positive plates, so that a cell with 18 positives would have 9 negatives. They have now standardised the manufacture of these cells, and it remains to be seen how it will compete with the lead sulphuric acid cell. The mean voltage of discharge amounts to something like 1·1 to 1·3 volts, so that double the number of Edison cells are required for the same voltage. The specific energy output is said to be about 15 watt-hours per lb. of cell, whereas English pasted types average something like 10 to 12 watt-hours per lb. With regard to Mr. Churton's remarks as to the behaviour of the plates when taken out of the cell and allowed to stand in air and then replaced. This treatment is very bad for the plates, and the result would be a heavy sulphating at the surface of the plates. This sulphate would no doubt grow in the form of crystals, and would be more or less impervious to the penetrating action of the acid, so that when the plates are replaced in the acid the result would be that the resistance for a time would be very considerable indeed, owing to the layer of lead sulphate crystals, but by a series of charges and discharges it could be got rid of, providing the action had not gone too far. The expense of charging, however, might be more than the cost of a new set of plates. On account of the formation of these crystals it is extremely detrimental to allow a battery to remain in a discharged condition. Replying to the last question, there are some instances in this country in which an engine has been employed to drive an alternator for lighting and a DC dynamo for charging cells during periods of light load, the peaks of heavy load being taken by the alternator run by the dynamo used as a motor, and supplied from the cells. With regard to the low energy efficiencies given in the table, the efficiency obtained in a laboratory test on a secondary cell is always higher than that obtained in practice. The efficiencies obtained, which are given in the table, are the result of continuous charges and discharges. The kind of use that a battery gets in practice is very Mr. Parr.

Mr. Parr. often coupled with periods of rest partly in a discharged condition. This increases the local action, and in turn diminishes the capacity and output of the cell. As an average the energy efficiency of a central station battery should be easily maintained at 60 to 65 per cent., unless it is not well looked after. I quite agree with Mr. Roles that an ampere-hour efficiency of 92 to 94 per cent. is easily possible, but the ampere-hour efficiency entirely depends on the current density at the plates. I have known batteries to give as much as 97 per cent., but the current density has been low, and under such a condition these high rates can be obtained, but directly a high current density is used the ampere-hour efficiency decreases. I have no doubt about the injurious effects of impurities, and that is why I have undertaken the present series of tests. Some of the impurities, as indicated by the curves, are very deadly indeed, and Mr. R. W. Vicarey has found that ammonia, which, of course, represents nitrogen compounds, is also deadly, at all events in large percentages. With regard to testing two or more cells together, as each cell reaches the lowest limit of voltage, namely, 1·8, it is cut out. They all therefore have the same treatment, but they are not all tested together.

ORIGINAL COMMUNICATION.

(*Received October, 1905.*)

NEW IRON-CORED INSTRUMENTS FOR ALTERNATE-CURRENT WORKING.

By W. E. SUMPNER, D.Sc., Member.

SUMMARY.—Introduction—Magnitude Errors—Phase Errors—Iron-cored Instruments—The Phase Error allowable—Ammeters—Ammeter Tests—Voltmeters—Voltmeter Tests—Wattmeters and Air-gap Transformers—Wattmeter Tests—Phase Meters and Idle Current Ammeters—Electromagnets for Moving-coil Instruments—Conclusion.

APPENDIX—1. System of Notation. 2. Theory of the Voltmeter. 3. Theory of the Hysteresis Phase Error.

In view of the long acknowledged excellence of direct-current instruments of the permanent magnet moving-coil type, remarkably little attention has been given to the possibility of constructing instruments on similar lines for alternate-current working. The permanent magnet must necessarily be replaced by an electromagnet, and this will need an additional current circuit. But this in itself is no disadvantage with alternating-current instruments, which must be of the double current, or double voltage, type, so that two circuits are needed in any case. The writer has already discussed this question in an address delivered as Chairman of the Birmingham Local Section (see *Journal*, vol. 34, p. 144). Numerous experiments made before and since that address have led to the decided opinion that the difficulties to be surmounted before it is possible to construct accurate iron-cored instruments for alternate-current working can all be overcome by the application of a few principles, and by close attention to detail.

The difficulties to be met are important, but they may be briefly stated, and they fall naturally into two classes :—

(i.) The induction density in the air-gap of the electromagnet, or the current through the moving coil, may not be of correct *magnitude* owing to the direct or indirect effects of eddy currents, or to variations in the permeability of the iron.

(ii.) The gap flux density and the moving-coil current may not be in proper *phase* relation, owing to the *phase error* introduced by the hysteresis in the iron, or by the influence of varying frequency and wave-form on the reactance of the instrument circuits.

Of the errors which fall under these two heads, by far the most important are those of the second class. Errors of the first type only really affect the calibration of the instrument. This is almost true even with wattmeters, since the effect of the errors is only slightly dependent on the power-factor of the load. We shall consider the errors in the order given.

MAGNITUDE ERRORS.

As regards the effects of eddy currents, it is sufficient to say that these can be made negligible for all usual frequencies by suitable lamination, so that no trouble need arise from their action.

The effects of varying permeability are largely neutralised owing to the presence of the air-gap. With ordinary dimensions suitable for instruments the reluctance of the air-gap is so great compared with that of the iron path of the magnetic circuit that a considerable change in the permeability of the latter only slightly influences the reluctance of the whole circuit, provided it is assumed that the mode of distribution of the flux is unaltered. But the most important effect of variations in the permeability seems to be an indirect one, due to variation in the leakage factor for different magnetising currents—that is to say, to variation in the mode of distribution of the flux. The leakage factor, or the ratio of the total flux, to that portion of it crossing the air-gap traversed by the moving coil, is much greater with small electromagnets of instrument dimensions than it is with dynamos, since the air-gap is a much larger proportion of the length of the iron path. It may reach very high values, especially if the magnetising coil is not wound right up to the boundary of the gap. Its value is rarely less than 2, and may easily be over 5 if the iron surfaces are much exposed in the neighbourhood of the gap. Now, so far as the accuracy of the instrument is concerned, it will not matter in the least what value the leakage factor has provided, it is the same for different currents. (For an ammeter it need not even be constant, since its variation can only affect the calibration of the scale.) But the leakage factor varies with the permeability of the iron, and thus it changes with the current, and it becomes difficult to keep the leakage factor, and the reluctance of the magnetic circuit, sufficiently constant in cases in which such constancy is needed. For an ammeter, as already stated, no difficulty arises, because the moving coil is never in the same part of the gap for two different currents, and hence the instrument can always be correctly calibrated; but for a wattmeter the circumstances are very different, since the same deflection is required for currents of very different magnitude provided the power being measured is the same, and it follows that the density of the lines for each part of the air-gap must not only be precisely determined by the current, but must also be strictly proportional to it at every instant.

Now in order to keep the reluctance of any induction path sufficiently constant it is necessary to have a fairly large air-gap, though not one undesirably great, for an instrument. We shall, however, see later that in order to overcome the error due to hysteresis the gap must be still further increased, so that to get a high flux density in the gap a con-

siderable magnetising force will be needed, and the advantage of an iron core largely neutralised. On the other hand, in order to keep the leakage factor constant so that the induction paths are fixed it is necessary either to use a very short air-gap (a condition most desirable to secure, but one incompatible with the above), or else to wind the magnetising coil completely *over the gap* so as to compel any lines in the iron to traverse the whole of the iron path. This last condition is difficult to secure in instruments without giving up the advantage of strong fields, but one easy to fulfil with an accessory such as the air-gap transformer used with the writer's wattmeter.

So far we have considered merely the series electromagnet, which of course is the only one possible to use for an ammeter. On the other hand, a shunt magnet must necessarily be used for a voltmeter, while either a shunt or series magnet may be used for wattmeters or phase-meters. It will be seen later that with the shunt magnet the difficulties to be surmounted take quite a different form from those mentioned, and that the conditions for accuracy can much more easily be met. One of these conditions is that the air-gap should have as small a reluctance as possible, which is fortunately also the condition which makes it easy to produce a strong magnetic field and a sensitive instrument.

Phase Errors.

Passing now to errors of the second class, or phase errors, we have to consider the influences at work which tend to prevent the current in the moving coil, and the magnetic flux in which this coil moves, from being in the correct phase relation. These phase errors will, especially in wattmeters, have a much more serious effect upon the accuracy of the instrument than any likely variation of the field flux from its proper magnitude. The successful construction of accurate iron-cored instruments for alternate-current working chiefly depends upon the possibility of reducing these phase errors to sufficiently small amounts. Such errors arise mainly from two causes: (1) Hysteresis makes the field flux differ in phase from the magnetising current, and (2) the reactance of the moving-coil circuit introduces a phase error. Of these two errors the former is independent of frequency and is but slightly dependent on current or wave-form, while the latter is greatly affected by both frequency and wave-form. It may be desirable to state here that by the phase difference between any two alternating-current quantities is meant the angle separating the vectors representing those quantities in the ordinary vector diagrams commonly used when discussing alternating-current problems. The author showed several years ago that the accuracy of this vector method is quite independent of the law of variation of the currents and potentials; and in the present paper no assumption is made as to the way in which the currents vary with time.

Iron-Cored Instruments.

Let us suppose for the present that the errors mentioned have been made negligible. Figs. 1 to 4 show diagrammatically the electrical

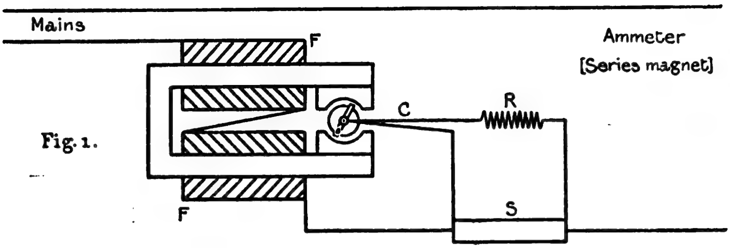


Fig. 1.

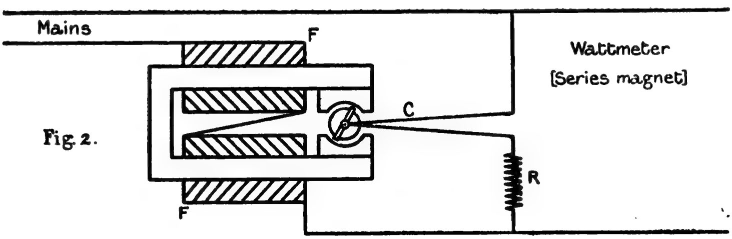


Fig. 2.

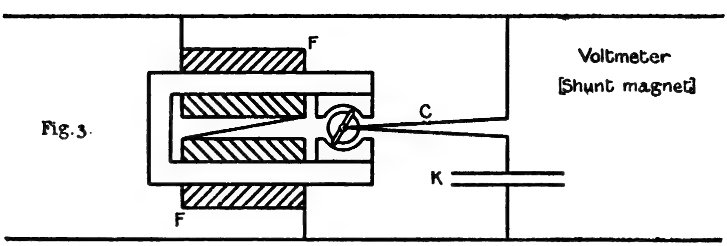


Fig. 3.

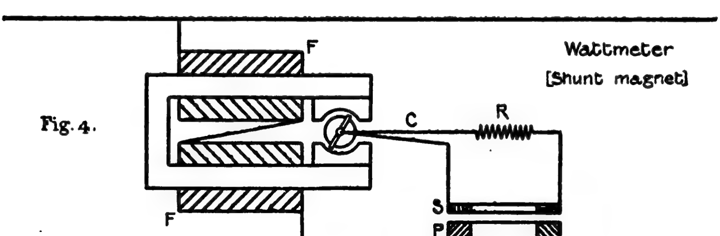


Fig. 4.

connections for (1) an ammeter, (2) a wattmeter with series magnet, (3) a voltmeter, and (4) a wattmeter with shunt magnet.

In Fig. 1 the magnetising coil is placed in series with a suitable non-inductive low resistance S, the terminals of which are connected with the moving coil through a non-inductive high resistance R. The magnetic flux and the moving-coil current C will each be essentially proportional to the main current, and hence the instrument can be calibrated as an ammeter, and its range varied by altering R.

Fig. 2 represents the series magnet form of wattmetter. Here the main current is used to produce the field, and the moving coil is shunted to the mains through a non-inductive resistance R, as with ordinary dynamometer-type wattmeters. The phase error due to frequency and wave-form is no greater than with instruments of the usual type, but there is, in addition, a phase error due to hysteresis, and also a magnitude error if the flux in the gap does not strictly measure the magnitude of the current.

In Fig. 3 a shunt magnet is excited by the voltage of the circuit, and the moving coil is put in series with a condenser K across the same mains.

In this case, assuming the resistance of the shunt winding is negligible, the back voltage induced in the iron must exactly balance the voltage of the mains, or the latter is an exact measure of the rate of change of the flux whatever the hysteresis of the core may be. This flux is thus in quadrature with the voltage, and proportional to it in magnitude. The moving-coil current is also in quadrature with the voltage in consequence of the action of the condenser K. The current and the magnetic flux are in the same phase, and their product is proportional to the square of the voltage. If the frequency or wave-form varies it can be shown that the product in question is unaltered so long as the mean square of the voltage remains constant, so that the indications of the instrument are independent of frequency and wave-form. The range can be altered by changing the condenser, or by varying the turns on the moving or magnetising coils, or by using the latter as a transformer for the moving-coil circuit.

Fig. 4 represents the wattmeter previously described by the writer. A shunt magnet is used to produce the field, and a special transformer, P S, is used to enable the main current through its primary coil P to produce a suitable current in the moving coil-circuit. As already stated in connection with the voltmeter of Fig. 3, the field F in the gap is in quadrature with the voltage V, and it is necessary to have the moving-coil current C in quadrature with the main current A, if the phase difference between F and C is to correspond with the power-factor of the load represented by the average product of V A. Such a result can be obtained by passing the load current through the primary P of a transformer P S, whose magnetic circuit has a constant reluctance like an air-core transformer, and whose secondary circuit is made essentially non-inductive by connecting the secondary coil S, and the moving coil, in series with a sufficiently large non-inductive resistance R. If the phase errors are made sufficiently small the

instrument will act correctly whatever the frequency or wave-form, and however the voltage and current vary in magnitude.

The Phase Error Allowable.

Before forming any estimate of the amount of the phase errors, it will be useful to consider what is the allowable value they may have in any particular instrument. This will vary greatly in accordance with the use to which the instrument is to be put. Let us first consider the case of an ammeter. Suppose F, the flux density in the gap, and C, the moving-coil current, have each been made proportional to the main current A. If there is no phase difference between F and C, the torque on the moving coil will be F C, and a measure of A^2, but if there is a phase error θ, the torque will be F C cos θ. Now, it will not matter at all what θ is provided it has the same value (for the current A considered) as when the instrument was calibrated. But supposing, owing to hysteresis or frequency effects, θ varies from its assumed value θ_0, to some other value $\theta + \theta_0$, the instrument, instead of reading the current A, will read a current A_1, where—

$$A_1^2 \cos \theta_0 = A^2 \cos (\theta + \theta_0) ;$$

or assuming $\theta_0 = 0$, we find—

$$A_1 = A (1 - \tfrac{1}{4}\theta^2),$$

and the error ε, or the difference between A and A_1 as compared with A, will be (if θ is a small fraction of a radian)—

$$\varepsilon = \frac{A - A_1}{A} = \tfrac{1}{4}\theta^2.$$

Now even if θ is as large as 10 per cent. of a radian, or 5·73°, the error will only be $\frac{1}{4}$ per cent., and the instrument will read correctly to 1 per cent. if θ remains less than 20 per cent. of a radian, or 11·5°.

A similar argument applies to the voltmeter, and the allowable phase error is the same.

But for a wattmeter a totally different state of things obtains. Assume as before that the magnitudes of F and C are correct, and represent in one case the voltage, and in the other the current of the load to be measured. Let the power-factor of this load be cos ϕ, but suppose that the phase difference between F and C, instead of being ϕ, is $\phi - \theta$ where θ is the phase error. The ratio of the actual to the true reading will then be—

$$\frac{\cos (\phi - \theta)}{\cos \phi}$$

and for small values of θ the error as a fraction of the true power will be—

$$\varepsilon = \theta \tan \phi.$$

This is an error of a much more serious character than that which obtains with ammeters and voltmeters, for it is proportional to θ instead

of θ^2, where θ is a small quantity, and it is moreover proportional to $\tan\phi$, which becomes large for low power-factors. Since the error of a wattmeter depends upon the power-factor, it is convenient to take the error at a particular power-factor to represent generally the wattmeter error. The most convenient power-factor to choose is evidently that for which $\tan\phi = 1$ and $\cos\phi = 0{\cdot}707$, since in this case the wattmeter error as a fraction of the true reading is equal to the phase error θ, and the power-factor in question is as useful and representative a one as could well be chosen.

It will be at once seen that θ must not exceed 1 per cent. of a radian, or $0{\cdot}57^\circ$, if the wattmeter error is to be reduced to 1 per cent., or the allowable phase error in a wattmeter is less than a twentieth of the allowable phase error in an ammeter or voltmeter to secure the accuracy stated. The ratio of the allowable phase errors is even more striking if the accuracy aimed at is greater, for if the errors are to be no more than 0·1 per cent. in each case, the phase error of the ammeter may be sixty-three times that of the wattmeter. Put in another way, if the phase error of an ammeter or voltmeter is no greater than that causing a wattmeter to be in error by 0·1 per cent. on a load of power-factor 0·71, the readings of the two former instruments are only affected by phase errors to the extent of one part in 40,000. The fact is that the ammeter and voltmeter shown in Figs. 1 and 3 are essentially wattmeters on non-inductive load, and their phase errors only produce negligible effects as with wattmeters under these conditions.

If the construction of accurate iron-cored ammeters and voltmeters be regarded as difficult, it would appear to be impossible to construct a good wattmeter on similar lines. On the other hand, if the wattmeter problem is solvable, the problem of ammeters and voltmeters should prove easy. It is the latter view which is correct.

It would have been simpler to solve the ammeter and voltmeter problems before attacking that of the wattmeter, but the latter instrument as indicated in Fig. 4 was the first the writer experimented with, and it was afterwards only natural to find that an instrument which proved satisfactory in action under the difficult conditions of a wattmeter, could be used with even greater accuracy as an ammeter or as a voltmeter with suitable circuit connections as represented in Figs. 1 and 3.

Ammeters.

If now the influences tending to cause error in the ammeter be carefully examined, it is striking how little effect they seem to have. Eddy currents can be made negligible by suitable lamination. The direct or indirect effects of varying permeability have no other result than to alter the calibration curve of the instrument. The flux density at a particular part of the air-gap may not be proportional to the current, but it is only necessary for its magnitude to be fixed by that of the current, and so be the same as that occurring for this current during the calibration of the instrument. Varying permeability has

merely the same effect on the instrument readings as an alteration in the shape of the air-gap. Hysteresis will cause a phase error, as also will reactance in the moving-coil circuit. The phase error due to hysteresis is independent of the frequency of the current, but is dependent to some extent upon the maximum value reached by the flux density in the iron. It is dependent but slightly on the magnitude of the current, and still less on its wave-form. It of course depends upon the hysteresis properties of the iron, and can be reduced by using good iron, and by enlarging the gap. But whatever its value may be, if it is always the same for a particular current, it can only have the effect of altering the calibration of the instrument. In nearly all cases the error seems to be negligible with ammeters. It is certainly a fact that an electromagnet ammeter of the type shown in Fig. 1 may have an hysteresis error altogether intolerable for direct-current working, and yet when used with alternate currents will not show any measurable error at all. The complete theory of the hysteresis phase error is intricate, and is dealt with in the Appendix, but the reason why it introduces no large error into the working of ammeters can be seen in a very simple way.

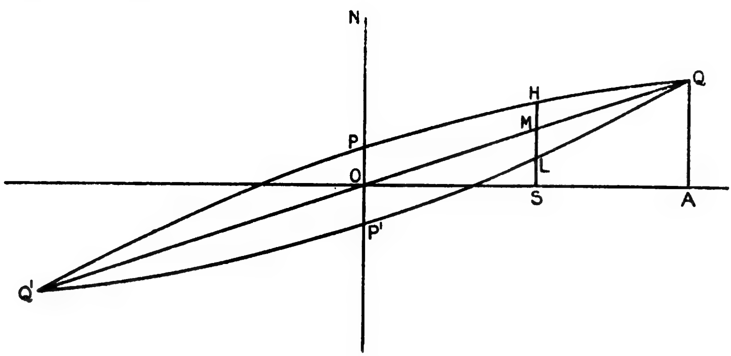


FIG. 5.

If the hysteresis curve be drawn for the cycle of current considered, it will be found to take the form of an elongated loop, as in Fig. 5, owing to the influence of the air-gap, and its ascending and descending portions will not differ greatly from that of the median line Q′ O Q. For any instantaneous value O S of the current, the moving-coil current, which we may assume proportional to O S, will be represented by M S, while the corresponding ordinates L S and H S of the ascending and descending portions of the loop will represent the two values of the field flux for the current O S. Since the mean of H S and L S is very approximately M S, the mean torque on the moving coil will be represented by the average value of the square of M S, just as if there were no hysteresis at all. This theory, though only approximate, represents essentially what happens in an ammeter. It is only when the moving-coil current is representing some alternating-current quantity differing from the

magnetising current in both phase and wave-form that the hysteresis difficulty becomes serious.

Ammeter Tests.

To test the foregoing theory, experiments were made on an instrument designed not as an ammeter but as a wattmeter. The instrument was essentially the same as that already described (*Journal*, vol. 34, p. 157), but the air-gap was reduced to ⅛ of an inch, and there were only 10 turns on the moving coil instead of 60 as in the former instrument, and a winding of 20 turns was put round the magnet for use as a series coil in addition to the shunt winding of 1,000 turns. The shape of the stampings used for the magnetic circuit is shown in Fig. 6. About 100 of such stampings were used, forming a block about 1¼ in. in depth. The connections as an ammeter were as indicated in Fig. 1, F being the field coil of 20 turns, S a resistance of 0·1

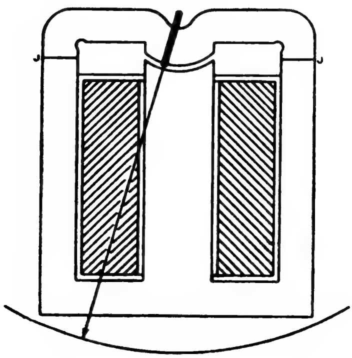


Fig. 6.

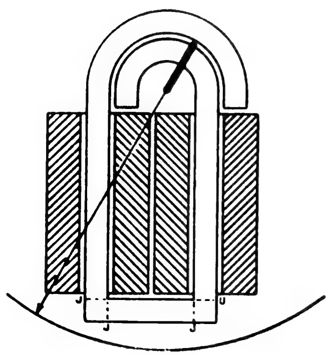


Fig. 7.

ohm, and R a resistance of 140 ohms. Currents up to about 15 amperes were passed through the ammeter, thus formed, in series with a Siemens dynamometer reading one revolution (of 400 divisions) for about 19 amperes. The calibration curve of the new instrument was determined by the direct-current method, by comparing the deflections for different currents through the moving coil while a constant current was maintained through the field magnet coil. From these tests a direct-reading scale was prepared. This was such that the marking was 40 for an angular deflection of exactly 40°, and the scale reading for other deflections was in all cases approximately the same as the angular deflections in degrees. The scale was prepared for use as a wattmeter, so that, just as with a Siemens dynamometer wattmeter, the reading should measure the square of the current or voltage, when the instrument was used as an ammeter or as a voltmeter respectively.

The first thing tested was the influence of previous history of magnetisation. The instrument when used with direct currents showed large hysteresis effects. Thus, in spite of the modifying influence of

the air-gap, the residual magnetism was from 10 to 20 per cent. of the maximum flux produced by a steady current such as to magnetise the iron to the extent intended in practice. But for alternating currents of a frequency of 90 cycles per second no difference could be detected, on the deflection caused by a current A, as measured, before and after the application of a large current B. Thus for A = 7·5 amperes, and B = 22 amperes, the current A, as measured by the Siemens instrument, always produced the same deflection on the new instrument. To test this for smaller currents, a hot-wire ammeter reading to 0·3 ampere was used to measure a small current of about a quarter of an ampere passed through the iron-cored instrument of Fig. 1, the resistances R and S being altered to obtain a good deflection. Under these circumstances the most careful observation failed to detect any influence of an alternating current of 15 amperes passed through the magnet winding, in making the instrument reading for 0·25 ampere differ from that obtained before the passage of the larger current.

Readings were then taken for different currents and frequencies in order to see how far the scale calibrated by the direct-current method could be relied upon as a measure of the currents used. It was soon evident that the error for different frequencies was so slight that its measurement would be difficult with non-reflecting instruments. After a number of preliminary trials two sets of tests were taken with current frequencies of 90 cycles and 30 cycles. These frequencies were about the highest and lowest which could be used under reasonably steady conditions with the apparatus available. The standard used was the Siemens dynamometer already mentioned. Current readings were taken for deflections of the iron-cored instrument at, or very close to, 20, 30, 40, 50, 60, and 70 divisions, these readings corresponding approximately with the deflection of the pointer in actual degrees. The corresponding readings of the dynamometer varied from about 80 to 260 on a scale for which 400 divisions corresponded with a complete revolution. The pointer of the iron-cored instrument was more than twice the length of that of the dynamometer, so that all the readings corresponded with appreciable movements of the pointer. In order to secure greater accuracy each observation was taken three times, and the numbers given in the following tables only show the mean values so obtained.

The first table gives the corresponding readings of the iron-cored and Siemens dynamometers for different currents at 90 cycles per second.

TABLE I.

Iron-cored dynamometer	23·0	29·8	41·15	52·05	62·6	67·5
Siemens „ ...	89·7	116·2	159·5	202·2	243	261·5
Ratio of readings ...	3·90	3·90	3·88	3·88	3·88	3·87

These tests show that the direct-current mode of calibration produces a scale which closely represents the relations between the magnitude of the alternating current and the reading of the pointer for the corresponding deflection. The effects of varying permeability and hysteresis do not seem to have altered the scale of the instrument, although the air-gap is a short one, and the hysteresis effects with direct-current working are considerable.

The readings shown in Table I. are simply the first of four sets of readings taken at 90 and 30 cycles respectively. Readings were taken every 10 divisions upwards from 20–70 for the first set at 90 cycles, then downwards from 70–20 for a second set; and for the third and fourth sets the observations were repeated at 30 cycles. Table II. shows the results, but only the ratios of the readings of the two instruments are given. It must be borne in mind that each ratio represents the mean obtained from three tests. The last two columns give the mean ratios obtained from the four sets of tests.

TABLE II.

<table>
<tr><th rowspan="2">Reading. Near.</th><th colspan="4">Ratios of Readings.</th><th colspan="2">Means.</th></tr>
<tr><th>90 ∿</th><th>90 ∿</th><th>30 ∿</th><th>30 ∿</th><th>90 ∿</th><th>30 ∿</th></tr>
<tr><td>20</td><td>3·90</td><td>3·86</td><td>3·88</td><td>3·85</td><td>3·88</td><td>3·86</td></tr>
<tr><td>30</td><td>3·90</td><td>3·92</td><td>3·83</td><td>3·85</td><td>3·91</td><td>3·84</td></tr>
<tr><td>40</td><td>3·88</td><td>3·91</td><td>3·78</td><td>3·78</td><td>3·89</td><td>3·78</td></tr>
<tr><td>50</td><td>3·88</td><td>3·90</td><td>3·81</td><td>3·78</td><td>3·89</td><td>3·79</td></tr>
<tr><td>60</td><td>3·88</td><td>3·88</td><td>3·78</td><td>3·79</td><td>3·88</td><td>3·78</td></tr>
<tr><td>70</td><td colspan="2">3·87</td><td colspan="2">3·74</td><td>3·87</td><td>3·74</td></tr>
</table>

The experimental conditions could not be kept as steady as was desirable in such a test, but the numbers in the above table are sufficient to establish the two following conclusions :—

(1) The calibration of the instrument by the direct-current method yields a scale applicable for alternate currents of any frequency, and is such that the scale reading is proportional to the square of the alternating current producing the corresponding deflection. This follows from the fact that all the numbers in any one of the columns of Table II. are essentially equal.

(2) The constant to be used with such a scale varies slightly with the current frequency in the case of the instrument tested. This can be seen by comparing the numbers in any row of Table II.

The numbers given in the table denote the ratio of the reading of the Siemens dynamometer to that of the iron-cored instrument.

The sensitiveness of the latter is thus greatest when the ratio is least, that is when the frequency is low. But it will be seen that the variation is small. Thus taking the readings near 40 divisions as typical, the constant varies from 3·895 to 3·780, or 2·96 per cent., but as the readings represent the square of the current, the error in estimating the current strength is only half this, or 1·48 per cent., and this for a change in frequency of 90 to 30 cycles. For all ordinary changes in frequency to which an instrument would be actually submitted the change of constant would be entirely negligible.

It must also be remembered that the instrument was wound for use as a wattmeter, with a shunt coil of 1,000 turns, occupying nearly all the available winding space. An extra winding of 20 turns was provided for series working, the wire being of the same diameter as that of the shunt coil. It occupied less than 2 per cent. of the available winding space, and was not distributed in the best way to control the leakage factor, since it only covered a small portion of the magnet limb. The frequency error found, although negligibly small for practical purposes, is far too large to be accounted for by the lag in phase produced in the moving-coil circuit due to inductance, since the calculated amount of this phase error is far too small; but there may be an indirect effect of this inductance owing to the voltage induced in the moving-coil circuit by the changing magnetism of the electro-magnet; there is also a possible calibration error due to variation of leakage factor since the series coil only covered a small portion of the core, and the scale was prepared from direct-current tests using the shunt winding for excitation. To further test these points, the shunt winding of 1,000 turns was used as a series coil, and was put in series directly with the 10 turns of the moving coil, thus forming a dynamometer suitable for very small currents. Some difficulty occurred in finding a suitable instrument to test the action of this dynamometer for small alternating currents up to about 50 milliamperes, but ultimately a Weston dynamometer voltmeter, made by Messrs. Elliott, was found to answer. This instrument read up to 60 volts, and had a resistance of 1,074 ohms, so that the readings on the scale of volts denoted currents approximately in milliamperes, and were accurately proportional to these currents even if the resistance of the coils increased due to heating.

The two instruments were put in series and tested with alternating currents of frequencies 40 cycles and 100 cycles. The current was adjusted to get about the same deflection in each test. Three sets of tests were taken, the first at 100 cycles, the second at 40 cycles, and the third at 100 cycles. Each of the numbers given in Table III. is the mean of many observations, and is given to the fourth significant figure, though of course it was not possible to read any single observation to such a degree of accuracy.

The dynamometer constant was obtained in each case by dividing the reading of the Weston instrument by the square root of the corresponding reading of the iron-cored instrument. The greatest difference of constant found for a range of frequency of 40 cycles to

TABLE III.

Weston voltmeter	46·30	46·07	45·63
Iron-cored dynamometer ...	32·07	32·00	31·27
Frequency	100	40	100
Dynamometer constant ...	8·177	8·147	8·160

100 cycles is only one-third of 1 per cent., and is within the error of reading of non-reflecting instruments with scales of ordinary length.

In the writer's opinion there can be no reasonable doubt that it is possible to construct accurate iron-cored ammeters for alternate-current working, and that their indications can be made independent of the effects of hysteresis and of variations in permeability, frequency and wave-form. The scale readings can also be controlled by suitably shaping the air-gap in accordance with well-known principles.

VOLTMETERS.

The electromagnet of a voltmeter must necessarily be used as a shunt to the mains, and as its inductance will be large, the magnetising current will for all usual frequencies be nearly in quadrature with the voltage producing it. At first sight this may seem a disadvantage, but closer attention will show that it renders the problem simpler. Referring to Fig. 3, if $\mathbf{V}$ is the voltage causing the magnetising current $\mathbf{A}_m$ in the field coil F, we have—

$$\mathbf{V} = r\,\mathbf{A}_m + \lambda \frac{d\mathbf{B}}{dt}$$

where r is the resistance of the winding; $\lambda\,\mathbf{B}$ is the total magnetic flux in the field coil, and $\mathbf{B}$ is the flux density in a particular part of the air-gap. It is assumed that λ is constant, or that the total flux is proportional to the flux density in the air-gap.

The moving-coil current $\mathbf{C}$ is produced by shunting a condenser of capacity K to the mains. If there is any loss of energy in this condenser, we shall assume it is due to a leakage current of resistance R. We thus have—

$$\mathbf{C} = \frac{\mathbf{V}}{\mathrm{R}} + \mathrm{K}\frac{d\mathbf{V}}{dt}.$$

The complete theory is discussed in the Appendix. For the present we assume that the field magnet winding has been so designed that the copper drop $r\,\mathrm{A}_m$ is a negligible fraction of V. If we put r equal to 0, we have—

$$\mathbf{V} = \lambda \frac{d\mathbf{B}}{dt}.$$

Now the torque acting on the moving coil is proportional to—

$$\frac{1}{T}\int_0^T \mathbf{B}\,\mathbf{C}\,dt,$$

where T is the periodic time.

If we substitute for $\mathbf{C}$ this becomes—

$$\frac{1}{T}\int_0^T \mathbf{B}\left(\frac{\mathbf{V}}{R} + K\,\frac{d\mathbf{V}}{dt}\right) dt = \frac{1}{RT}\int_0^T \mathbf{B}\mathbf{V}\,dt + \frac{K}{T}\int_0^T \mathbf{B}\,\frac{d\mathbf{V}}{dt}\,dt.$$

Now

$$\int_0^T \mathbf{B}\,\mathbf{V}\,dt = \lambda\int_0^T \mathbf{B}\,\frac{d\mathbf{B}}{dt}\,dt = 0,$$

Since $\mathbf{B}$ and $\mathbf{B}^2$ are cyclic functions of period T, also if we integrate by parts we find—

$$\int_0^T \mathbf{B}\,\frac{d\mathbf{V}}{dt}\,dt = [\mathbf{B}\mathbf{V}]_0^T - \int_0^T \mathbf{V}\,\frac{d\mathbf{B}}{dt}\,dt = -\int_0^T \mathbf{V}\,\frac{d\mathbf{B}}{dt}\,dt,$$

since the product $\mathbf{B}\mathbf{V}$ is a cyclic function of period T. Hence the torque is measured by

$$\frac{K}{T}\int_0^T \mathbf{V}\,\frac{d\mathbf{B}}{dt}\,dt = \frac{K}{\lambda}\,\frac{1}{T}\int_0^T \mathbf{V}^2\,dt = \frac{K}{\lambda}\,V^2,$$

since

$$\mathbf{V} = \lambda\,\frac{d\mathbf{B}}{dt}.$$

Hence the torque is proportional to V^2, the mean square of $\mathbf{V}$ throughout the period; and this is true, whatever the frequency or wave-form, however leaky the condenser may be, and whatever the permeability or hysteresis characteristics of the iron. The instrument can be calibrated like an ordinary dynamometer voltmeter. In order to make the copper drop rA_m negligible compared with V, we want to increase the inductance of the coil as much as possible. This implies a narrow air-gap, a most welcome condition, since the narrower the gap the easier it is to increase the flux density and to secure a sensitive instrument.

The more complete theory given in the Appendix shows that the error in reading the volts, as compared with the true voltage reading, assuming no phase errors, is given by the formula—

$$\varepsilon = \tfrac{1}{2}\,\theta_r\,[\theta_r + \theta_i + \theta_c],$$

where θ_r is the phase error due to the resistance or copper drop;
θ_i „ „ „ hysteresis in the iron;
θ_c „ „ „ condenser power-factor;

θ_r can easily be reduced to 1 per cent. of a radian for ordinary frequencies. The instrument indicated in Fig. 6 has a copper drop of this value for currents having a frequency of 50 cycles per second. θ_c is numerically equal to the power-factor of the condenser, and in ordinary cases may be taken as 2 per cent. θ_i is a quantity more difficult to forecast. Its value for electromagnets having short air-gaps will usually vary from 5 to 20 per cent. The value of ϵ in the above formula thus works out, in general, to about 1 part in 2,000, and is unreadably small. Moreover, it is only the variation of this quantity which has to be considered as an error. None of the above phase errors varies with the voltage to any appreciable extent, so that the instrument constant once determined will be correct. No variations of frequency or wave-form can alter ϵ sufficiently to cause an error in the reading. In fact θ_i and θ_c are independent of frequency, and almost so of wave-form, while θ_r diminishes as the frequency increases; so that the presence of harmonics in the wave-form will tend to diminish ϵ.

Voltmeter Tests.

The numbers given in Table IV. show the result of an early set of tests made on an iron-cored instrument connected up as a voltmeter,

TABLE IV.

f	V	D	$\sqrt{D}$	$V/\sqrt{D}$
100	90	106	10·3	8·74
"	78·1	80·5	8·98	8·75
"	64	53	7·28	8·79
"	54·3	37·5	6·12	8·86
"	41·4	21	4·58	9·03
80	33·1	13·5	3·67	9
"	46·7	27·6	5·26	8·89
"	68	61	7·82	8·71
"	79	82	9·06	8·72
"	88	101	10·05	8·75
35	48·2	30	5·48	8·80
"	49·3	31	5·57	8·85
"	70·7	66·7	8·17	8·67
"	90	105	10·25	8·78
"	92·3	110	10·5	8·80

as in Fig. 3. This instrument was constructed of stampings shaped as shown in Fig. 8. The magnetising coil consisted of 990 turns, and the moving coil of 60 turns. The resistance of the former was 2·53 ohms, and the magnetising current for 98 volts at 80 cycles was 0·178 ampere, so that the copper drop was 0·46 per cent. at 80 cycles, or about 0·74 per cent. at 50 cycles. The condenser used was a standard of half-microfarad capacity. The instrument was compared with a hot-wire

voltmeter reading to about 120 volts, and provided with a mirror to enable the position of the pointer to be more accurately read. Tests were made at different parts of the scale for current frequencies of 100, 80, and 35 cycles per second. In the table, f denotes the frequency, V the reading of the hot-wire voltmeter, and D the deflection of the iron-cored instrument. The last two columns show the calculated values of $\sqrt{D}$ and of $V/\sqrt{D}$ respectively. The numbers obtained for the last quantity should be constant if the instrument is correctly calibrated, and if this acts accurately for different frequencies. A direct-reading dynamometer scale had been prepared for the iron-cored instrument on the basis of a calibration by direct currents. This was such that a deflection of 80 degrees was marked 80, and other deflections in accordance with the calibration. The air-gap was such that the deflection in degrees was nearly proportional to the corresponding scale marking, and the instrument had a working range of over 120 degrees.

At the time these observations were made they were regarded as quite satisfactory, since V was merely plotted against $\sqrt{D}$, and the points were found to lie closely on a straight line. When later the values of $V/\sqrt{D}$ were worked out, the ratios obtained were not found in such close agreement as theory would lead one to expect. With one exception the only bad results are for low readings on the scale, for which neither instrument could be read very accurately. The above tests consisted merely of a few observations, and it was evident that to sufficiently test the effect of change of frequency it was necessary to eliminate observational errors and calibration errors in the instruments by taking a number of tests at about the same deflection for different frequencies. For this purpose the instrument illustrated in Fig. 6 was used in conjunction with a standard condenser of 1 microfarad capacity. It was tested against a hot-wire instrument reading up to 65 volts. A number of readings were taken, all in the neighbourhood of 50 volts, the means being as shown in Table V.

TABLE V.

Number of Tests ...	5	4	7	8	8
Frequency ...	37	90	90	37	90
Voltage V... ...	50·10	50·55	50·15	50·25	50·60
Reading D ...	52·2	52·8	52·0	52·3	52·6
$V/\sqrt{D}$	6·934	6·956	6·953	6·948	6·977

The mean values obtained for $V/\sqrt{D}$ for the frequencies 37 and 90 cycles are respectively 6·941 and 6·962—a difference of only 0·3 per cent.

To further test this question a common condenser of about 3 microfarads capacity was used with the instrument of Fig. 6. A hot-wire voltmeter reading to 30 volts was used as the standard, and a large number of tests were taken in the neighbourhood of 29 volts. The results are summarised in Table VI., only the mean of the readings being given for each set of tests.

TABLE VI.

Number of Tests	6	10	8
Frequency	37	90	37
Voltage V	28·58	28·78	29·08
Reading D	49·75	50·21	51·25
$V/\sqrt{D}$	4·052	4·061	4·061

In these tests the values found for the ratio $V/\sqrt{D}$ only differ from the mean by 5 parts in 4,000, or by 0·12 per cent. for a range of frequency of 37 to 90 cyles. The difference is in the same direction as that found in the tests of Table V. But the differences found in the two sets of tests are exceedingly small. The deflection of one of the instruments was only about 5 inches measured along the scale, and 0·2 per cent. of 5 inches is only one-quarter of a millimetre. The tests thus only prove that the frequency error is too small to be read on any ordinary non-reflecting instrument; and this conclusion is quite in accordance with the theory above given, which indicates that the error cannot exceed 1 part in 2,000, or 0·05 per cent.

Wattmeters.

The electromagnet for a wattmeter may be used in series with, or in shunt to, the mains. In either case the phase errors must be reduced to much smaller values than are necessary for ammeters and voltmeters. If the small phase error be θ, the wattmeter, instead of reading the true value

$$V A \cos \phi,$$

will read

$$V A[\cos \phi - \theta \sin \phi],$$

where $\cos \phi$ is the power-factor, and ϕ is negative for leading currents. For wattmeters of the series-magnet type θ is negative, but is positive for shunt-magnet instruments. Thus for lagging currents the series-magnet instrument will read high, and the shunt-magnet instrument low. The percentage error will be $\theta \tan \phi$, but the error as a reading will be $\theta \sin \phi$ in terms of the deflection produced by the same current and voltage assuming a non-inductive load. If the phase error θ of the wattmeter be 1 per cent. of a radian, and if the load be 100 volt-

amperes, the numbers in Table VII. show the errors for different power-factors.

TABLE VII.

WATTMETER ERROR FOR A LOAD OF 100 VOLT-AMPERES (FOR A PHASE ERROR OF 1 PER CENT. OF A RADIAN).

$\cos\phi$. Power-Factor.	$100\cos\phi$. True Watts.	$100\,\theta\sin\phi$. Error in Watts.	$\theta\tan\phi$. Error per Cent.
1·0	100	0·01	0·01
0·9	90	0·44	0·49
0·8	80	0·60	0·75
0·707	70·7	0·707	1·00
0·6	60	0·80	1·33
0·5	50	0·87	1·73
0·4	40	0·92	2·30
0·3	30	0·95	3·17
0·2	20	0·98	4·9
0·1	10	0·99	9·9
0·02	2	0·9998	50·0

It will be seen that the error as a reading is fairly constant except for high power-factors, and the error per cent. increases, as the power-factor diminishes, mainly because the true reading itself diminishes. For most commercial instruments the full scale reading is only produced for the full load current at the normal voltage, assuming the load non-inductive. Hence, if the phase error θ is 1 per cent., the error as a scale reading can never exceed 1 per cent. of the scale length, however low the power-factor. Also the error per cent. is numerically equal to θ for a load of power-factor 0·707, for which $\tan\phi$ is unity. Thus the phase error θ, reckoned as a percentage of a radian, is a good general measure of the wattmeter error.

For the series-magnet type of wattmeter it is difficult, if not impossible, to reduce the hysteresis phase error to 1 per cent. without increasing the air-gap to such an extent that the advantage of an iron-cored instrument is entirely lost. For shunt-magnet instruments it is, however, much easier to bring about this result, and the shorter the air-gap is made the smaller the resulting phase error will be, so that the condition for accuracy is the same as that for securing a sensitive instrument. A current transformer must be used in conjunction with the shunt type wattmeter, and, if this transformer is to have an iron core, or shield, to protect its coils from the action of stray fields, the hysteresis difficulty of the series-magnet again crops up. But the object to be attained is now very different. With a moving-coil instrument the reason for nearly closing the air-gap is to secure a strong field. For the transformer a strong field is not necessary. Indeed, ample sensitiveness can be secured without using iron at all,

since the power absorbed by the current in the moving-coil circuit is minute in the extreme. The iron is only needed to shield the coils from stray fields, though it is also advantageous in reducing the size of the transformer. It is thus possible to have a large air-gap and to sufficiently diminish the hysteresis phase error.

Two interesting wattmeters having iron-cored electromagnets of the series type have recently been described. One of these is Dr. Drysdale's instrument, made by Messrs. Nalder Bros. (*Electrician*, vol. 55, p. 472), and the other is due to Signor C. Olivetti, of Milan (*Electrician*, vol. 54, p. 1050).

The length of the magnetic circuit in the former instrument appears to be about thirty times the length of the air-gap. In the latter instrument this ratio is stated to be about 12. The writer has no information as to the magnitude of the phase errors of these instruments, but a large number of tests made on several transformers having iron cores with air-gaps have led to the conclusion that the air-gap should be greater than those corresponding with the above ratios. Of course everything depends upon the degree of accuracy aimed at.

The theory of the shunt-magnet wattmeter has already been given (see *Journal*, vol. 34, pp. 167–170). The phase error θ is given by the formula—

$$\theta = \theta_r + \theta_s + \theta_t,$$

where

θ_r is the phase error due to resistance or copper drop,
θ_s „ „ „ inductance of the moving-coil circuit,
θ_t „ „ „ hysteresis in the transformer.

The equation is really a vector equation; θ cannot be greater than the numerical sum of the three phase errors mentioned, but it may be less.

The phase error θ_r due to copper drop can easily be determined for any instrument, by measuring (1) the resistance r of the magnetising coil, and (2) the current A_m produced through this coil by a voltage V alternating at any known frequency. Thus for one of two instruments constructed of stampings shaped as shown in Fig. 6, r was 3·07 ohms, and 95 volts at 81 cycles produced a magnetising current of 0·21 ampere. θ_r for 81 cycles works out to be 0·68 per cent., and can be easily calculated for any other frequency from the fact that it is inversely proportional to frequency. The value of θ_r at 50 cycles was found to be 1·1 and 1·08 per cent. for two instruments made in accordance with Fig. 6, and about 0·73 per cent. for each of three instruments made in accordance with Fig. 8. An instrument made in accordance with Fig. 7 was found to have a copper-drop error of only 0·5 per cent. at 50 cycles. The instrument indicated in Fig. 9 has not yet been constructed, but this design is such that large polar extensions are possible, and the portion of the air-gap not traversed by the moving coil can be made very narrow.

The value of θ_r can be reduced by diminishing the length of the air-gap, and by increasing the section of the gap as compared with that

of the core either by extending the poles as in Fig. 7, or by expanding the pole-pieces, as shown in Figs. 8 and 9.

In Figs. 6 to 9, and also in Figs. 11 to 18, unshaded areas denote iron stampings, while shaded areas represent the section of the winding. The diagonal shading is of two kinds to indicate the direction

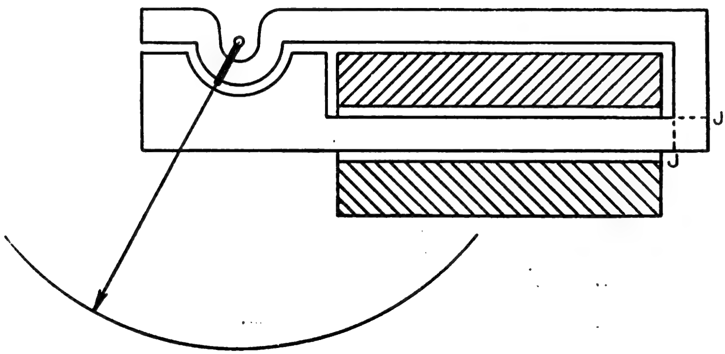


FIG. 8.

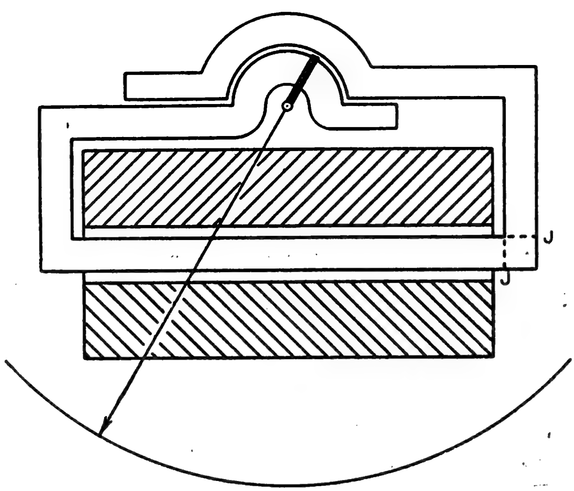


FIG. 9.

of the current. Joints in the magnetic circuits are indicated at J, butt joints by full lines, and broken joints by dotted lines. These joints are important both from a constructional point of view, and from the magnetic reluctance they represent.

The phase error θ_s, due to the inductance of the moving-coil circuit is Lp/R, where L is the coefficient of self-induction, and R the resist-

ance of this circuit, and where p is the current frequency multiplied by 2π. The moving coil in the instruments made consisted of very few turns, so that L was almost entirely due to the self-induction of the secondary of the current transformer. Assuming no magnetic leakage between the primary and secondary coils of the latter, it can easily be proved that—

$$\theta_s = \frac{Lp}{R} = \frac{n_2 a_2}{n_1 a_1},$$

where a_1 and a_2 are the primary and secondary currents, and n_1 and n_2 are the primary and secondary turns respectively. The value of θ_s is thus the ratio of the ampere-turns associated with the secondary and primary circuits, and this ratio must be kept low. There is no difficulty with air-core transformers in reducing it to less than 0·2 per cent. With a transformer having an iron core with an air-gap, the conditions for sufficiently reducing the hysteresis error are such that the ratio of the ampere-turns must in nearly all cases be much less than the figure just given, and hence θ_s can be neglected for such transformers if the hysteresis error has been reduced to reasonable values. The simplest way to find the value of θ_s in the case of a transformer is to calculate the ratio of the ampere-turns used in the two circuits for a particular non-inductive load. The value of n_1/n_2 is known, a_1 the load current is observed, and a_2 can be calculated from the deflection of the wattmeter on a non-inductive load, and from the applied voltage and current frequency, since the calibration of the instrument by the direct-current method gives for any deflection the product of the magnetising and moving-coil currents, and this product will be very closely the same for alternating currents as for direct ones.

The phase error due to inductance can with ease be reduced to a negligible quantity. In the six instruments as yet constructed the lowest value attained for the phase error due to copper drop has been 0·5 per cent. for currents at 50 cycles. But the way to further reduce this error is quite clear. The air-gap can be extended in cross section as in Fig. 9, and its length from iron to iron can be greatly reduced in that portion of the gap not traversed by the moving coil. The weights of iron and copper used for the magnet can also be increased, and in this way the copper drop error can be reduced to any extent desired.

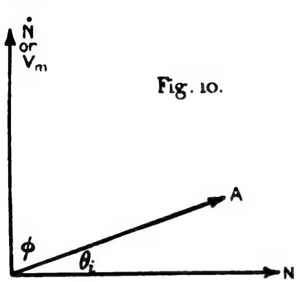


Fig. 10.

But the reduction of the phase error θ_i, due to hysteresis in the current transformer, proves to be a much more difficult matter. The complete theory of this phase error is complicated, and is dealt with in the mathematical appendix.

The controlling factor is the loss of energy in the iron. If the vectors representing the magnetising current **A**, the flux of magnetism **N**, and the voltage $\mathbf{V}_m$, be denoted by the lines so marked in Fig. 10

the vectors $\mathbf{V}_m$ and $\mathbf{N}$ are always perpendicular to each other, since $\mathbf{V}_m$ is proportional to $\dot{\mathbf{N}}$, the rate of change of $\mathbf{N}$. If ϕ and θ are the angles between the vector $\mathbf{A}$, and the vectors $\mathbf{V}_m$ and $\mathbf{N}$ respectively, these angles are complementary except for extraordinary wave-forms, for which the vector $\mathbf{A}$ lies outside the plane determined by $\mathbf{V}_m$ and $\mathbf{N}$. If the three vectors cannot be regarded as coplanar, it follows from solid geometry that θ_t is *greater* than $\frac{\pi}{2} - \phi$. Thus, if we can determine ϕ we can find the *minimum* value of the phase error θ_t. Now $\cos\phi$ is the power-factor of the magnetising current, assuming the resistance of the magnetising coil is negligible. Thus if we know w the watts lost in the *iron* due to the application of a voltage V producing a magnetising current A, we have—

$$\text{Cos}\,\phi = \frac{w}{\text{VA}}$$

and from this the minimum value of θ_t can be found.

The electromagnet of the wattmeter illustrated in Fig. 6 was tested for iron losses by a method which eliminated from the measurement the losses due to the resistance of the winding (see *Journal*, vol. 34, p. 154). The test showed that the iron losses at 100 volts 100 cycles amounted to 4·2 watts, corresponding with 2·1 watts at 50 volts and 50 cycles. The magnetising current for 94 volts at 81 cycles was 0·21 ampere, or 0·181 ampere for 50 volts at 50 cycles. Hence—

$$\text{Cos}\,\phi = \frac{2{\cdot}1}{50 \times {\cdot}181} = {\cdot}232.$$

and this is the *minimum* value of $\sin\theta_t$.

It follows that θ_t exceeds 13 degrees, and is about 23 per cent. of a radian. It would thus be hopeless to use the electromagnet of Fig. 6 for a wattmeter of the *series* type, since the phase error θ_t must for accurate working be reduced to less than 1 per cent. of a radian.

The length of the magnetic circuit illustrated in Fig. 6 is roughly 130 times the length of the air-gap. The phase error θ_t of an electromagnet intended for series working can only be reduced by increasing the length of the air-gap or shortening the iron path of the lines. For a given mass of a particular kind of iron,* magnetised to the extent desired, by means of an alternating current of fixed frequency, the loss of power, w, is an irreducible minimum. The product V A is independent of the number of turns used in the coil if the length of the air-gap is fixed.

For a given winding, and flux density, V is fixed as well as w, so that the only way to reduce $\cos\phi$ and $\sin\theta_t$ is by increasing the air-gap, and making it necessary to have a large number of ampere-turns to produce the required flux density. This consideration tells against the use of the series-magnet for a wattmeter, since with a large air-gap the advantage of an iron core is largely neutralised. It also implies that the current transformer for an instrument of the shunt-magnet

* All the iron used for the transformers and instruments referred to in the present paper was obtained from Messrs. Sankey, of Bilston, and consisted of stampings of their insulated Lohys iron.

type should, if an iron core be used, have an air-gap certainly not less than one-tenth of the length of the magnetic circuit.

For portable standard instruments, and for ordinary test-room working, it is quite unnecessary to use iron-cored transformers. Magnetic disturbances can easily be avoided in such cases, and the readiness with which an air-core transformer can be constructed for any required range of currents is a great convenience for ordinary laboratory purposes. For switchboard work a shielded transformer is desirable, and this is quite possible to make for accurate work if not constructed on too small a scale. It is possible to make one amply sensitive, and as small in size as a cubic inch, for any ordinary current range. But to reduce the hysteresis phase error, it is necessary to provide sufficient space for a primary winding suitable for from 500 to 1,000 ampere-turns for full-load current, and to pay due attention to the ratio of the length of the air-gap to that of the magnetic circuit.

The investigation of these iron-cored transformers, of which a dozen have been made to different designs, has proved a long and troublesome matter. The various tests made upon them have occupied far more time than that spent in testing all the instruments mentioned in the present paper. Considerations of space prevent more than the briefest allusion to the experiments made upon them in connection with the tests given below.

The chief points to be noted about these transformers are illustrated in Figs. 11 to 18. The expanded pole area of the air-gap in Fig. 11 ensures a magnetic circuit of constant reluctance. In one transformer of this type the reluctance was found constant to 1 part in 1,000 for a current range of 10 to 1. But the hysteresis phase error was far too large. On cutting off the polar extensions, as in Fig. 12, the phase error was much reduced, but was still found too great, and it was also found that the reluctance was not sufficiently constant. This was also the case, though not to such a marked extent, for the transformer shown in Fig. 13, in which only the inner air-gap was surrounded with wire. The leakage factor is sufficiently controlled by surrounding all three gaps with wire as in Fig. 14, but this design is rather wasteful in copper. A greatly improved design is shown in Fig. 15, in which the side gaps are closed up and the centre gap correspondingly lengthened. Another form of this construction is shown in Fig. 16. This requires less copper than that of Fig. 15, but, on the other hand, the centre gap must be lengthened as the pole area is extended, so that more iron is required. The best shielded type of transformer is shown in Fig. 17, and the most accurate type of all is the ironless unshielded form shown in Fig. 18.* Air-core transformers can readily be made without involving appreciable heat loss, or impedance; and they can much more easily be placed in a position free from the action of stray fields than the equally unshielded wattmeters usually found on switchboards. It is also possible to construct air-core transformers so as to be

* In this connection it is important to note that accurate commercial wattmeters of the series dynamometer type have their coils either unshielded as in Fig. 18, or simply surrounded by a shell of laminated iron as in Fig. 17.

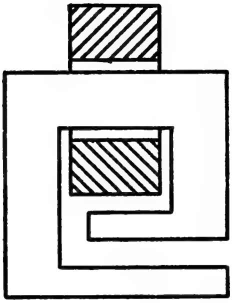


Fig. 11.

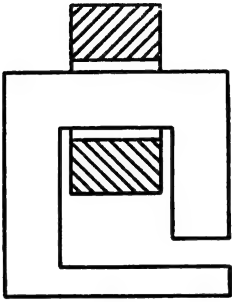


Fig. 12.

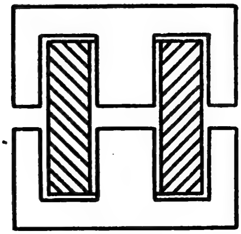


Fig. 13.

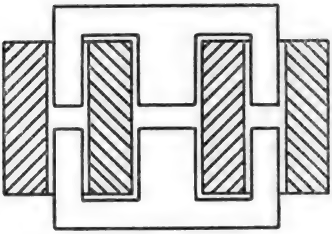


Fig. 14.

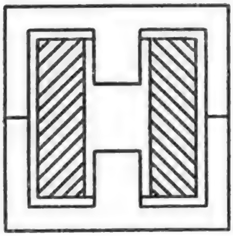


Fig. 15.

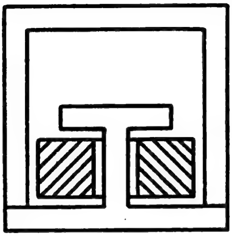


Fig. 16.

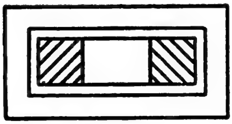


Fig. 17.

Fig. 18.

unaffected by stray fields, either by winding them as endless solenoids, or as long solenoids with ends magnetically short-circuited by a few strips of thin iron. In some cases the "kicking coil" used for lighting protection might possibly be further utilised in this way.

Wattmeter Tests.

The figures in Table VIII. show the result of some early tests made on the wattmeter of Fig. 6, to investigate the effect of change of frequency, f, and voltage, V, for non-inductive loads. The standard instrument used was a Mather-Duddell wattmeter with 9,000 ohms in series with its pressure coil. The readings of the instrument are shown in the column headed M.D.W., and those of the iron-cored wattmeter in that headed I.C.W. The scale of the Mather-Duddell instrument reads 100 divisions for a complete revolution. Some of the current readings, taken with an ordinary ammeter, are given in the column headed A. The important readings were those of the two wattmeters. These readings were taken with care, and each number given represents the mean of three tests. The ratio of the readings is shown in the last column.

TABLE VIII.

f	A	V	M.D.W.	I.C.W.	Ratio.
30·5	8·2	38	36·2	38·4	1·062
42	8·0	50	46·6	49·3	1·058
42	8·0	50	46·1	49·0	1·063
53	5·8	63	45·8	48·7	1·063
76·5	5·9	66	47·5	50·3	1·058
86·5	—	103	33·7	35·4	1·050
96·5	—	115	43·0	45·4	1·055
97	—	117	43·3	45·6	1·053
97	—	86	42·8	45·2	1·056

In these tests it will be seen that in round numbers the frequency varied from 30 to 100 cycles, and the voltage from 40 to 120 volts, and that the constant of the instrument was not effected to any appreciable extent.

The current transformer used in these and the immediately succeeding tests had an iron core with two air-gaps in series. Its construction is represented by Fig. 14. The primary winding had nearly 200 turns. The secondary winding was of 40 turns, and was put in series with the moving coil and with a resistance of 120 ohms. The number of ampere-turns used with the primary winding was large and well over 1,000 in all the tests. The result of a comparison of the same two instruments on inductive and non-inductive loads is next given. A small rotary converter with six slip-rings was supplied with direct-current power, and used to produce the alternate voltages required. The voltage circuits were in some tests supplied

from the same slip-rings as the load current, and in others from a separate pair of slip-rings. The phase difference of the voltages produced at the two pairs of slip-rings was carefully measured and found to correspond with a power-factor of 0·298, and this was taken to be the power-factor of the load current in reference to the voltage used for the pressure circuits. The frequency was kept constant at 50 cycles. The load consisted of a bank of lamps in series with the primary of the current transformer, and the series coils of the Mather-Duddell instrument.

Five sets of readings were taken for loads alternately non-inductive and inductive. Each set consisted of three or four tests all at about the same deflection. The mean values found for the ratios of the readings of the new instrument and the standard were successively

1·076, 1·120, 1·073, 1·113, 1·072.

The means of these are 1·074 and 1·116, differing by 3·76 per cent.

The power-factor $\cos\phi$ being 0·3, for which $\tan\phi = 3·17$, the total phase error obtained by dividing 3·76 by 3·17 works out to be 1·19 per cent. of a radian. Now the copper drop in the magnetising coil at 50 cycles accounts for 1·09 per cent., and the phase error due to the inductance of the moving-coil circuit was calculated, from the known ratio of the ampere-turns, to be 0·034 per cent., leaving only about 0·07 per cent. as the phase error due to hysteresis. The result was regarded as most satisfactory until, some months afterwards, the figures were critically examined, in consequence of subsequent tests, which revealed the difficulty of attaining such small errors with iron-cored transformers. The inductance of the primary of the transformer was investigated, and found to be sufficient to produce a small phase error, which although not important as regards the tests of Table VIII. (and indeed only such as to bring the readings at high frequencies into closer accord with those for low frequencies) was sufficient to produce a sensible effect on loads of low power-factor. It so happened that the slip-rings chosen for the current circuit yielded a voltage *leading* in reference to that supplied by the slip-rings used for the pressure circuits of the instruments. This, though not suspected at the time the tests were made, was evidenced by the fact that the new instrument gave relatively higher readings for the inductive than for the non-inductive load, showing (for instruments of this type) that the current was leading in reference to the voltage of the pressure circuits. The inductance of the transformer primary thus made the phase of the current approach that of the voltage, and the power-factor of this current was in consequence higher than 0·3 corresponding with the phase difference of the slip-ring voltages. On repeating and confirming the tests, but measuring the power-factor from a comparison of the readings of the standard instrument with those of volts and amperes for the two loads, it was found that the total phase error, instead of being 1·19 per cent. at 50 cycles, was 2·3 per cent. at that frequency. After allowing for the phase errors due to copper drop and inductance, there remains a phase error of about 1·2 per cent. due to the hysteresis of this particular transformer.

The tests shown in Table IX. refer to the same wattmeter used with an air-core transformer, having 40 turns on the primary suitable for currents up to 15 amperes. The secondary consisted of 100 turns, the inductance of which was such that for currents of 50 cycles the value of Lp was 0·24, where L is the coefficient of self-induction and p is $2\pi f$ or 100π. This coil has a resistance of 6·4 ohms, and was put in series with the moving coil (resistance 2·4 ohms) and an extra resistance of 37 ohms. The total resistance of the secondary circuit was 45·8 ohms, so that the phase error due to inductance was 0·24/45·8, or 0·52 per cent. The phase error due to copper drop was 1·09 per cent. for 50 cycles, so that the total phase error as calculated was 1·61 per cent.

The instrument was tested against a standard Weston wattmeter suitable for currents up to 5 amperes. Different voltages and currents were used, but the power-factor of the load was maintained constant, either at unity, or at 0·5, by means of two coupled alternators in fixed phase relation. The frequency was kept constant at 50 cycles. The current was adjusted to give certain fixed readings on the standard, and the corresponding readings on the new iron-cored instrument (I.C.W.) were observed. Sets of observations were taken either at constant voltage or at constant current to test the calibration throughout the scale. In each case 3 or 4 readings were taken, the numbers given in the table being the means. The last column shows the ratio of corresponding readings of the two wattmeters.

TABLE IX.

Power-Factor.	Volts.	Watts.	I.C.W.	Ratio.
1·0	101	240	40·15	·1675
,,	,,	200	33·05	·1652
,,	,,	160	26·7	·1670
,,	,,	120	20·0	·1666
,,	,,	80	13·3	·1660
,,	,,	40	7·0	·175
,,	,,	240	39·9	·1665
,,	,,	300	49·7	·1658
,,	120	240	39·9	·1665
,,	101·5	200	33·1	·1655
,,	82	160	26·8	·1675
,,	62·5	120	20·1	·1675
,,	44	80	13·2	·1652
,,	23	40	6·75	·1685
0·5	103	240	41·2	·1715
,,	,,	200	34·1	·1705
,,	,,	160	27·4	·1712
,,	,,	120	20·5	·1710
,,	,,	80	13·7	·1713
,,	,,	40	7·2	·1800
,,	52	160	27·4	·1712
,,	,,	80	13·5	·1690

Except for the low readings the ratios found are very consistent for constant power-factor. It should be remembered that the readings of the I.C.W. depend upon a direct-current calibration and approximately give the deflections of the pointer in degrees, the reading being 40 for exactly 40 degrees. If all the readings for less than 100 watts be disregarded, it will be found that the means of the ratios in the last column are 0·1665 and 0·1711 for the two sets of readings. These numbers differ by 46 in 1665 or by 2·76 per cent. Now for a power-factor $\cos\phi = 0\cdot5$ the value of $\tan\phi$ is $\sqrt{3}$ or 1·732, and if we divide 2·76 by 1·732 we find the total phase error to be 1·592 per cent. The value calculated above from the measured values of the copper drop and the inductance is 1·61 per cent., in almost perfect agreement. Such close coincidence is no doubt somewhat accidental, especially since the power-factor of the load was not very carefully measured; but a large number of tests have been made at various times on the wattmeter in conjunction with air-core transformers, and the agreement between the phase errors as predicted and as determined from the readings of the wattmeter, has always proved satisfactory.

The tests shown in Table IX. were immediately succeeded by others on the same two instruments, but with an iron-cored transformer like Fig. 12 used in place of the air-core transformer. The primary turns were 80 in number, and the secondary coil contained 30 turns having a value for Lp equal to 0·053 at 50 cycles. The same external resistance of 37 ohms was used as with the former transformer, the total secondary resistance being about 41 ohms, so that the inductance phase error was 0·13 per cent. The copper-drop error was 1·09 per cent. as before, so that the phase error (apart from hysteresis) amounted to 1·22 per cent.

A complete set of tests similar to those in Table IX. was made on the two instruments under these conditions. The results plotted excellently on two straight lines connecting the reading of the I.C.W. with the true watts. One of these lines represented the tests for unity power-factor, and the other those for power-factor 0·5. By dividing as before the reading of the I.C.W. by the corresponding reading of the standard in watts, two sets of ratios were obtained. The means of these were 0·255 and 0·278, differing by 23 in 255, or by 9·0 per cent. On dividing by 1·732 as before to get the total phase error we obtain 5·2 per cent. as this quantity. The phase error due to inductance and copper drop is only 1·22 per cent., so that the hysteresis phase error is about 4 per cent. It is difficult to obtain any confirmation of this number except, as shown in the Appendix, by comparing it with measurements of the residual magnetism properties of the magnetic circuit of the transformer. The remanence ratio for this transformer was afterwards tested and found to be 4 per cent. at 1 ampere, 2·5 per cent. at 3 amperes, and 1 per cent. at 10 amperes. The currents used in the alternating tests varied from 0·5 to 3 amperes.

In another set of tests an iron-cored transformer like Fig. 13 was used, having a primary of 207 turns and a secondary of 40 turns. The inductance and resistance of the secondary circuit were such that at

50 cycles the phase error was 0·33 per cent. The same iron-cored wattmeter (Fig. 6) was tested against the Mather-Duddell standard, on circuits provided by two coupled alternators run at 50 cycles, and supplying currents in some tests leading, and in others lagging, in regard to the voltage used for the pressure circuit. The current was kept at about 5 amperes, and the voltages were varied from 50 to 150 to produce about the same deflections in all the tests. The essential results are shown in Table X. The columns show in succession—(1) whether the current was lagging or leading, (2) the power-factor cos ϕ calculated from the ratio of watts to volt-amperes, (3) the ratio of the wattmeter readings, (4) the percentage error of the constant of the new instrument as compared with its constant for non-inductive loads, (5) the value of tan ϕ, (6) the ratio of the percentage error to tan ϕ, or the total phase error.

TABLE X.

Current State.	Cos ϕ Power-Factor.	Ratio of Readings.	Error per Cent.	Tan ϕ.	Phase Error.
Non-inductive ...	1·0	1·20	0	0	0
Lagging... ...	0·31	1·31	9·17	3·28	2·80
„	0·785	1·22	1·67	0·79	2·12
Leading... ...	0·47	1·145	−4·58	−1·87	2·46
„	0·90	1·185	−1·25	−0·484	2·59
„	0·755	1·166	−2·83	−0·87	3·25

The numbers in the last column should be the same, but the difficulty of measuring these small errors must be borne in mind, and also the fact that only single observations were taken, so that the numbers given do not represent the mean of many tests as in previous cases. If the percentage errors be plotted against tan ϕ they will be found to lie very fairly on a straight line, the only bad point corresponding with the last test in the above table. The two tests most reliable are those for low power-factor and for the high percentage errors 9·17 and 4·58, since small percentage errors are more difficult to measure accurately. The mean phase error calculated from these two tests is 2·63 per cent. The copper drop accounts for 1·09 per cent., and the inductance error is 0·33 per cent., leaving about 1·2 per cent. for the hysteresis phase error. The remanence ratio for this transformer for a current of 5 amperes was afterwards found to be 0·9 per cent.

Another set of tests was taken with the same instruments as above with a non-inductive resistance in series with the shunt-magnet coil of the iron-cored instrument in order to artificially increase the copper

drop. The amount of this resistance was such as to increase the copper-drop error to 6·24 per cent. at 50 cycles. A number of tests were taken on loads of power-factors varying from 0·6 to 0·8, and compared with tests made on loads of unity power-factor. The percentage errors found were plotted against the corresponding power-factors, and from the curve so obtained the value of the percentage error for power-factor 0·707 was read off. This was found to be 7·35 per cent. The phase errors due to copper drop, and inductance, are 6·24 per cent. and 0·33 per cent. respectively, the sum of these numbers being 6·57 per cent. The difference is only about 0·8 per cent., and does not correspond well with the hysteresis phase error of 1·2 per cent. found in the preceding tests. But the tests could not, even with the greatest care, be taken so as to ensure accuracy to a tenth of 1 per cent., and though the difference is probably to be attributed to errors in measurement, there is no necessary inconsistency. For the phase errors, as already pointed out, add up, not as mere numbers, but as vectors, and the vector difference being small compared with the two nearly equal large values 7·35 and 6·57, may easily differ appreciably from the numerical difference without assuming any considerable angular divergence between the vectors. It must also be remembered that the phase error due to resistance is always less than the ratio of the copper drop to the applied voltage, and the difference becomes noticeable if there is appreciable hysteresis in the iron, and if the copper drop is large.

Numerous other tests made might be added, but those already given are sufficient to show that the errors of the wattmeter obey the formulæ given, and that the measured and calculated values agree as closely as can reasonably be expected in view of the difficulties of the tests.

A dozen iron-cored or air-gap transformers have been constructed to different designs, and each of these has been tested for hysteresis phase error. The values found have varied from about 8 per cent. to less than 1 per cent. of a radian, but in all cases its amount has been approximately equal to, though somewhat greater than, the corresponding value found for the remanence ratio of the transformer when considered simply as an electromagnet excited by a current through the primary coil. This remanence ratio, or remanence, is simply the ratio of the residual magnetism, on switching off the current, to the maximum magnetism produced by the current. The theory given in the Appendix shows that there is a close connection between the hysteresis phase error and this remanence ratio, and that the two quantities are approximately equal. The experimental tests quite bear out this theoretical result.* The amount of work

* In some of the tests the values found for these quantities appeared to differ considerably, but this result was ultimately traced to a variation with current of the reluctance of the magnetic circuit of the transformer. When the leakage factor of this magnetic circuit is held constant by suitable winding, or better still by using expanded pole-pieces at the gap, the reluctance has always been found sufficiently constant. In one case with expanded pole-pieces the variation was less than 1 part in 1,000 for a range of current of 10 to 1. Unfortunately such polar extensions increase the hysteresis phase error. With large air-gaps and exposed iron surfaces the reluctance has sometimes been found to vary 3 per cent. for the same range of current.

involved in testing these transformers and in finding the values of their phase errors, their induction constants, and their remanence ratios, has been considerable. The induction constants can quickly be determined by measuring with a hot-wire voltmeter the secondary voltage for a given primary current, or by making use of the known constants of the wattmeter and applying the formula given on p. 21. The measurement of the remanence, on the contrary, is quite as troublesome a matter as the determination of the phase error by means of careful tests of the wattmeter errors on loads of different power-factor. The remanence, being only of the order of 1 per cent., is difficult to measure with any accuracy by direct ballistic methods. It was done by using a compensation method, by constructing an air-core transformer having about the same mutual induction coefficient as the iron-cored transformer under test, putting the two primaries in series, and joining up the secondaries in opposition * in a circuit including a resistance and a sensitive ballistic galvanometer. The ordinary tests for a Ewing's hysteresis cycle could then be made and interpreted so as to determine not only the remanence, but also any slight variation, with current, of the reluctance of the magnetic circuit of the iron-cored transformer. The tests were greatly complicated by the facts that the remanence varies considerably, and the reluctance varies slightly with the strength of the maximum current used for the cycle, and also by the fact, pointed out by Ewing, Searle, and others, that for comparatively low induction densities the influence of previous magnetic history is very great, and before a true cyclic state can be attained a large number of current reversals must be made. Unfortunately, published researches on hysteresis are of little use in the present connection. The induction densities practicable in these iron-cored transformers are necessarily low owing to the influence of the considerable air-gap, and the data hitherto published about the hysteresis of iron at low induction densities are not nearly sufficient to form any useful guide for the present purpose. The classical paper of Professor Ewing and Miss Klassen (*Phil. Trans.* 1893, p. 985), although published so long ago, still constitutes the most valuable general guide to the hysteresis properties of iron; but in that research few tests were made for induction densities smaller than 1,000 C.G.S. units. It has been necessary in connection with these iron-cored transformers to make a large number of such tests, but they are not yet nearly complete, and limits of space prevent any allusion to them in the present paper. In the writer's opinion, however, there is no doubt that it is possible to construct these iron-cored transformers so as to have a phase error

* The same arrangement of apparatus, but with an alternating current passed through the two primaries, was subsequently found to be most suitable for the direct determination of the hysteresis phase error, since this angle is the phase difference between the two secondary voltages. The small angle required was measured by a special two-voltmeter method, with the aid of a delicate permanent magnet galvanometer and a nonsynchronous rectifier, as described by the present writer in "The Measurement of Small Differences of Phase," *Phil. Mag.*, 1905, p. 155. The values obtained by this method, for the hysteresis phase error of the different transformers, were in closer agreement with those deduced from the wattmeter tests than the corresponding values found for the remanence ratios of these transformers.

well under 1 per cent. of radian. In fact, it is almost obvious that if the laminated iron is used simply as a shield to totally surround the air-core transformer as in Fig. 17, the hysteresis phase error must become negligible.

The total phase error of wattmeters of the shunt-magnet type is easily reducible to less than 1 per cent. of a radian, and the instrument error for loads of different power-factors will thus be less than those indicated in Table VII.

Phase-meters and Idle-Current Ammeters.

Suppose a wattmeter of the shunt-magnet type to have its moving-coil current generated, not by a current transformer, but by tapping a non-inductive low resistance in series with the main current as indicated in Fig. 19, in which F represents the field-magnet coil connected

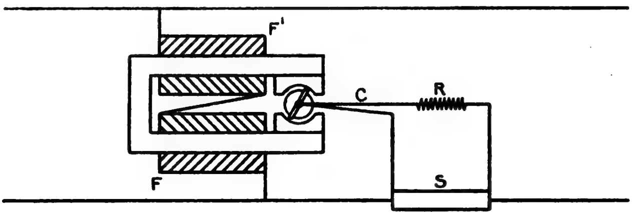


Fig. 19.

across the mains, S the non-inductive shunt, and R a suitable resistance to render the current C in the moving-coil circuit sufficiently non-inductive. The instrument will under these circumstances show no deflection at all on a non-inductive load, but for an inductive load of power-factor cos ϕ the deflection will measure

$$V A \sin \phi,$$

where V is the voltage, and A the load current. The reading will be inversely proportional to the frequency, but for circuits of constant voltage and frequency will measure simply A sin ϕ, the inductive component of the current, or the "idle current" as it is usually called.

Instruments for this purpose are used under the name of idle-current ammeters, and are employed instead of phase-meters to indicate the inductive nature of the load.

The theory and construction of phase-meters has been considered at length by the present writer in a paper recently published ("The Theory of Phase-meters," *Proc. Phys. Soc.*, October 27, 1905, also *Phil. Mag.*, January, 1906). In connection with the subject of the present paper it will suffice to state the chief results arrived at. These are as follow :—

(i.) Whatever may be the faults of phase-meters, not one of these need be due to the presence of iron in the magnetic circuits The use of iron in such circuits makes it possible to greatly increase the forces acting on the moving system. There is no counterbalancing disadvantage.

(ii.) Phase-meters for multi-phase circuits, if once correctly calibrated, are accurate on balanced loads for currents of all frequencies and wave-forms. Any errors are due to mechanical or extraneous causes, and chiefly arise from friction and other disturbing influences when the electro-magnetic forces are feeble.

(iii.) Phase-meters can be accurately calibrated for balanced multi-phase loads by a simple direct-current method of test.

(iv.) The error of phase-meters on unbalanced loads may be very large. It is by far the most serious error to which these instruments are liable. It may make the instrument read too high or too low, by an amount depending on the differences between each of the load currents and the mean value of these currents. If calibrated to read the power-factor $\cos \phi$ on balanced loads, the reading for loads which are out of balance will lie between the values $\cos \phi \pm \theta \sin \phi$, where the phase error θ is for most instruments approximately equal to the greatest fraction by which one of the load currents diverges from the mean value of the currents in the mains.

ELECTROMAGNETS FOR MOVING-COIL INSTRUMENTS.

The series form of electromagnet, when worked with direct currents, exhibits marked effects due to residual magnetism, magnetic history, and varying permeability. This is especially the case when the air-gap is small, a necessary condition for sensitive instruments. These characteristics, which are of course widely known and appreciated, have appeared to constitute such a formidable obstacle to the use of electromagnets for the purpose of accurate alternate-current instruments, that comparatively little attention has hitherto been devoted to the subject. Yet investigation shows that only for one instrument, the ammeter, is the series form of magnet necessary; and that in this special case the hysteresis effects, which would be so serious for direct-current working, automatically cancel out in a most striking manner when alternating currents are used, while variations in permeability only affect the calibration of the scale. For the other instruments the shunt form of electromagnet is to be preferred. In this case the phase error of the magnet arises from an entirely different cause, and is wholly due to the resistance of the magnetising coil. The hysteresis of the magnet may be considerable, but the magnetising current and the copper drop are thereby only slightly affected. The magnetism is directly controlled by the voltage. The magnetising current has to adjust itself to the flux determined by this voltage.

It is also remarkable that whether the series or shunt form of electromagnet be in question, the condition to be secured in the design is the same, so that, as shown above, the same instrument when suitably designed can be used indifferently as an ammeter, a voltmeter, or a wattmeter. This condition may be briefly summarised by stating that

the ratio of the copper drop to the voltage corresponding with the inductance or impedance of the coil must be made a fraction sufficiently small, but not smaller than actually needed to reduce the error and heat loss in the instrument. In all cases it is advantageous to diminish the resistance of the coil (including connecting leads if for a shunt winding) as much as possible consistent with the number of turns used, provided the weight of copper is kept within reasonable limits; but in some cases it is practicable to make the reluctance of the magnetic circuit too low, and the impedance of the coil too high, so that the current resulting from a given voltage applied to the coil is not enough to properly magnetise the magnet. In the case of the ammeter it is obvious that the lower the resistance the less the loss in the instrument, and the smaller the impedance the better so far as the effect on the circuit is concerned. With all the instruments the minimum length of air-gap is fairly well fixed by the clearance needed for the moving coil, and the density of lines desirable in the gap is also fairly definite, so that the number of ampere-turns needed for the magnetic circuit, which is determined essentially by the gap, may be regarded as more or less a constant in all cases. For an ammeter of given range this consideration determines the number of turns to be used. To diminish heat loss it is desirable to make the wire sufficiently thick, and to economise material the magnetic circuit should only be made long enough to enclose the coil. It is also advantageous for another reason to fill up with copper wire the space corresponding with the inner boundary of the magnetic circuit, since under these circumstances the leakage factor is held constant. It is always advantageous to diminish the copper drop, but there is no gain in increasing the core flux beyond that corresponding with the required flux density over the gap actually utilised by the moving coil. While it is true that the copper drop should be reduced to a minimum, and that the inductance of the coil must be made large, it is also a fact that the latter quantity, and therefore the inductance voltage, may be made greater than is necessary or desirable.

Consideration of the voltmeter leads to exactly the same mode of construction. For a given magnetic circuit the ratio of copper drop to applied voltage is independent of the number of turns, provided the same weight of copper is used for the coil; but the number of turns will be fixed by the flux required, by the voltage and by the frequency. If the copper drop can be sufficiently reduced with a coil which does not occupy the whole of the available winding space, economy of material dictates that the length of the iron circuit should be reduced, with a corresponding decrease in the iron losses. On the other hand, if the copper drop is too large, the length of iron must be increased to provide room for thicker wire, or, if the iron losses are not too great, the flux density in the core can be increased by extending the pole-pieces at the gap. But if the phase error due to resistance has been made sufficiently small it is a disadvantage to further increase the inductance of the coil, since this means either an unnecessary amount of iron, or a needlessly large loss in the core. For both ammeters and

voltmeters economy of material dictates a design such that the magnetising coil occupies the whole of the available winding space, but since it is easy with these instruments to secure sufficient accuracy with a small amount of material, an economical mode of construction is not so important as it is with wattmeters.

For the wattmeter the same considerations hold, but as it is necessary to reduce the resistance phase error to a much smaller amount than in the case of the voltmeter, it will be found desirable to increase the inductance of the coil, either by increasing the weight of iron and copper used, or by the employment of polar extensions at the gap. The upper limit desirable for this inductance will not be easily reached with the low frequencies now common, but it would be far otherwise in high-frequency work. Thus, if wattmeters of the shunt-magnet type were to be constructed for electrical oscillation circuits, or for the purposes of wireless telegraphy, the difficulty would not be to reduce the copper-drop error, which would become altogether negligible, but to sufficiently reduce the inductance of the coil to allow the passage of a current large enough to produce a reasonable flux density. So much would this be the case that possibly iron would not be needed in the magnetic circuits of such instruments, and indeed eddy-current effects in the iron would become serious.

In the instruments as yet constructed the control has been made as strong as, or stronger than, that used in ordinary commercial permanent magnet moving-coil instruments. For scientific purposes much greater sensitiveness can be secured in the usual way by weakening the control, and by the use of optical pointers. Even with the instruments actually made it has been possible to obtain a large angular deflection with the current through an ordinary Leyden jar produced by a voltage alternating at 50 cycles per second, with the magnet coil and moving-coil circuits in parallel. But when a small current or voltage to be measured has to be used also to excite the magnet, the practical limit of sensitiveness is really determined by the number of volt-amperes needed for this excitation. Thus, if 100 ampere-turns are needed to produce the flux density in the gap, the number of turns needed on the magnetising coil when the current is to be only one milliampere will be so excessive, that the voltage necessary will be quite out of the question. This will be apparent if the heat loss in the iron is assumed to be about half a watt, corresponding with about 5 volt-amperes. Similarly the current needed for a millivoltmeter will be quite impracticable if the iron loss is of about the same amount as assumed above. But if the magnet is separately excited from the alternating mains supplying the small current or voltage to be measured, no difficulty arises from lack of sensitiveness, though it may be necessary to take two measurements with the aid of suitable phase-changing devices. Thus if two known voltages in quadrature be applied in succession to the magnetising coil, the two rectangular components of the moving-coil current can be readily measured, and its phase and magnitude determined.

It seems natural to describe as iron-cored instruments those

referred to in this paper, but it would be even more appropriate to call them air-gap instruments. The function of the iron is to make it practicable to reduce the length of the air path of the magnetic lines to the minimum needed for the free motion of the moving coil, and thus to diminish the ampere-turns needed for the strong field in which the coil moves; or we may regard the iron as a convenient means of lengthening the magnetic circuit till it is sufficient to enclose the winding, without appreciably affecting the reluctance of this magnetic circuit. The high permeability of the iron enables this result to be achieved, and the assistance of the iron is invaluable from this point of view. But in all other respects the properties of the iron are disadvantageous. The behaviour of the instruments, or of such accessories as the iron-cored transformer, is really determined by the gap, and in the design of them this gap forms the most important consideration.

Conclusion.

A shunt-magnet wattmeter, such as described above, has properties in sharp contrast with those of a wattmeter of the ordinary dynamometer type. The voltage circuit is formed of thick wire, and the lower the resistance of it the better. The moving-coil circuit carrying the (transformed) current is formed of thin wire, and may contain a high resistance by adjusting which different ranges can be secured. Heavy overloads of current or voltage will not harm the instrument, and owing to the low current densities used in the magnetising coils the heating of these coils will be negligible. There may be a temporary increase in the iron losses due to the overload, but the constant of the instrument will be unaffected. The flux density in the gap is determined by the applied voltage and not by the properties of the iron, so that variations in permeability and hysteresis, or a gradual ageing effect in the core, will have no effect on the constant for non-inductive loads. Thus, if the reluctance of the gap is 25 times that of the core, a variation of 50 per cent. in the permeability of the latter will only alter the magnetising current by 2 per cent.; so that if the phase error due to copper drop is 1 per cent. in the first case, it will only be 1·02 per cent. in the second. The percentage error on loads of power-factor 0·7 will only be altered by 0·02 per cent. owing to the 50 per cent. change of permeability assumed, while the instrument constant will be quite unaltered for high power-factor loads.

The constant of the instrument is the same for all voltages and currents, and is independent of changes in frequency and form factor. The error on low power-factor loads is in the opposite direction to that found in ordinary wattmeters; also the percentage error becomes less the higher the frequency used, since the copper-drop phase error decreases with rise of frequency, and the inductance phase error, which increases with frequency, is relatively unimportant. This property is hardly an advantage, since the tendency is to use lower and lower frequencies in electrical work, but there is no difficulty in sufficiently reducing the phase error due to copper drop to meet ordinary working conditions.

In general behaviour and characteristics the instruments are very like permanent-magnet moving-coil instruments for direct-current circuits. In structure each consists of a light moving system placed in a strong magnetic field, and possesses all the advantages associated with instruments of this class. The moving coil is shielded from disturbances due to external fields. There is ample margin of sensitiveness, and by means of light accessory resistances, condensers, and transformers any range of working can be secured. Only small currents are used in the instrument coils, and the current transformer is always on practically open circuit as regards its secondary, so that it is possible by means of light switches to shift the instrument connections from one circuit to another, and to use it for different purposes, without affecting the main circuit. This cannot be so easily done with any other wattmeter. One of the advantages of these instruments is that brass, and other metal parts, can be used in the immediate neighbourhood of the moving-coil field, without loss of accuracy.

The instrument will not work at all on direct-current circuits. It would, in fact, short-circuit the mains. But the scale of the instrument can be calibrated by a direct-current method, and this is a great advantage. An alternating-current test must be made for the purpose of adjusting the constant till the scale reads correctly at one point.

Several instruments have been made and tested, but nearly all the tests recorded in this paper were made upon *one* instrument the scale of which was prepared from a direct-current test. The instrument was used as an ammeter, as a voltmeter, and as a wattmeter, the same scale being utilised in all cases. When used as a wattmeter the scale reading was always found proportional to the watts. When used as a voltmeter, or as an ammeter, the quantity to be measured (whether voltage or current) was always found proportional to the square root of the scale reading, as in the case of an ordinary Siemens dynamometer. Not only can the scales be so graduated that the instruments read correctly, but the law of these graduations can be determined without using alternating-current tests. As with all other instruments, there are sources of error. The purpose of the present investigation has been to examine every such source, to measure the resulting errors, and to find out the conditions under which they can be reduced to a minimum. The result is to show that so far as ammeters and voltmeters are concerned the errors can be made so small that the error in scale reading is too minute to be detected on a scale of ordinary length, and that the error of wattmeters can with good design be made sufficiently small to be negligible for practical purposes under ordinary conditions. What error there is, too, is of an exact and certain kind, and its amount can be predetermined with accuracy with the aid of a few simple tests on the instrument circuits. The main fact which stands out is that the great advantages associated with iron-cored magnetic circuits can be secured in alternating-current instruments in conjunction with accuracy.

In conclusion, the writer desires to express his thanks to Mr. G. Brown, the instrument maker at the Birmingham Technical School,

for careful and skilful construction of the instruments, and to Mr. F. W. Preston, one of the demonstrators in the Electrical Department, for his valuable assistance in connection with the very numerous tests which have been made, and of which those referred to in the present paper only form a small portion.

APPENDIX.

1. System of Notation.

We shall use a letter in heavy type, such as $\mathbf{V}$, to represent the instantaneous value of an alternating current quantity; and the same letter in lighter type, such as V, to denote the *magnitude*, or square root of mean square, of this quantity. Owing to the mathematical relationships between mean squares and mean products of any given variables, it follows that an equation between the corresponding values of two or more variables like $\mathbf{V}$ can be regarded as a vector equation,* and $\mathbf{V}$ may thus also be used to denote the corresponding vector.

The notation of the calculus may be conveniently simplified for the purpose of alternate-current problems by using Newton's fluxional notation, in which

$$\dot{\mathbf{V}} \equiv \frac{d\mathbf{V}}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and by using, instead of the ordinary signs of integration, a bar over any quantity $\mathbf{Q}$ to be integrated (or averaged) thus—

$$\overline{\mathbf{Q}} = \frac{1}{T}\int_0^T \mathbf{Q}\, dt \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where T is the periodic time. Every integral likely to occur will be a time integral taken over the period, and really a roundabout way of expressing a mean value or average for this period. Thus we have

$$\overline{\mathbf{V}\mathbf{A}} = \frac{1}{T}\int_0^T \mathbf{V}\,\mathbf{A}\, dt = \mathrm{V}\,\mathrm{A} \cos\phi \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where ϕ is the phase angle between the vectors $\mathbf{V}$ and $\mathbf{A}$.

Since V, the magnitude of $\mathbf{V}$, is a time average, and not a variable as regards time, there will be no ambiguity in using the symbol $\dot{\mathrm{V}}$ to represent the magnitude of $\dot{\mathbf{V}}$. Also whatever the wave-form we can put

$$\dot{\mathrm{V}} = p\,\mathrm{V} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where p is a quantity proportional to the frequency f for a given wave-form. It is $2\pi f$ for sine-waves, and for other wave-forms it is kf, where k is a constant which will differ very little from 2π, even if the sine law be widely departed from.

* See "Vector Properties of Alternating Currents," *Proc. Roy. Soc.*, vol. 61, p. 465.

For any two alternating-current quantities $\mathbf{A}$ and $\mathbf{B}$ we have

$$\mathbf{A}\dot{\mathbf{B}} + \mathbf{B}\dot{\mathbf{A}} = \frac{d}{dt}(\mathbf{A}\mathbf{B}),$$

or

$$\overline{\mathbf{A}\dot{\mathbf{B}}} + \overline{\mathbf{B}\dot{\mathbf{A}}} = \frac{1}{T}\int_0^T \frac{d(\mathbf{A}\mathbf{B})}{dt}\,dt = 0,$$

since the product $\mathbf{A}\mathbf{B}$ has the same value at the two limits of the integral. Hence we can always put

$$\overline{\mathbf{A}\dot{\mathbf{B}}} = -\overline{\mathbf{B}\dot{\mathbf{A}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

a special case of which is given by the equation

$$\overline{\mathbf{Q}\dot{\mathbf{Q}}} = 0,$$

whatever cyclic quantity may be represented by $\mathbf{Q}$.

2. Theory of Voltmeter.

For the magnetising coil we have

$$\mathbf{V} = r\mathbf{A}_m + \lambda\dot{\mathbf{B}} = \mathbf{v} + \mathbf{V}_m \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where $\mathbf{V}$ is the applied voltage, r the resistance of, and $\mathbf{A}_m$ the current through, the coil, and $\mathbf{V}_m$ the voltage self-induced in the coil by the changing magnetism.

Assuming the density of lines $\mathbf{B}$ in the gap to be proportional to the total flux, we have

$$\mathbf{V}_m = \lambda\dot{\mathbf{B}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

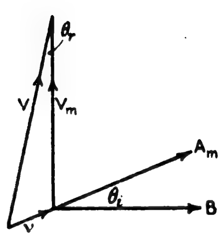


Fig. 20.

and we may put $\mathbf{v}$ for the "copper drop" $r\mathbf{A}_m$, which is necessarily perfectly in phase with the current $\mathbf{A}_m$. The vector diagram is shown in Fig. 20, in which θ_r is the phase difference between $\mathbf{V}$ and $\mathbf{V}_m$, and θ_i is that between the flux density $\mathbf{B}$ and the magnetising current $\mathbf{A}_m$. The vectors $\mathbf{B}$ and $\mathbf{V}_m$ are perpendicular since their mean product is zero in consequence of the relation

$$\overline{\mathbf{B}\dot{\mathbf{B}}} = 0.$$

For the moving-coil circuit we have

$$\mathbf{C} = \frac{\mathbf{V}}{R} + K\dot{\mathbf{V}} \quad \ldots \ldots \ldots \quad (8)$$

where K is the capacity of the condenser, the loss of energy in which is assumed to correspond with a small leakage current through a high resistance R. This leakage current is in quadrature with the capacity current, and is so small with a condenser (whose power-factor is usually about 0·02) that as regards the magnitude of C we may neglect the leakage current and put

and
$$\left.\begin{aligned} C &= K p_1 V \quad \text{from (4) and (8)} \\ V_m &= \lambda p_2 B \quad \text{from (7) and (4)} \end{aligned}\right\} \ldots \ldots \quad (9)$$

where p_1 and p_2 are each proportional to the frequency f, and for all ordinary wave-forms may be considered equal to one another and to $2\pi f$.

To get the magnitude of the copper drop we have from the figure (remembering that $\mathbf{B}$ and $\mathbf{V}_m$ are perpendicular)

$$\frac{v}{V} = \frac{\sin\theta_r}{\cos\theta_t} = \frac{\theta_r}{1 - \frac{1}{2}\theta_t^2}$$

or

$$v = \theta_r V \quad \ldots \ldots \ldots \quad (10)$$

since all the quantities θ are small, and we propose to neglect cubes, and triple products, of these quantities in comparison with unity.

To express the leakage resistance R in terms of θ_c, the power-factor of the condenser, we may proceed as follows:—

The power lost in the condenser is

$$\overline{\mathbf{C}\mathbf{V}} = C V \theta_c = K p_1 V^2 \theta_c \quad \text{from (9).}$$

But from (8) we have on multiplying by V and taking means—

$$\overline{\mathbf{C}\mathbf{V}} = \frac{1}{R}\overline{\mathbf{V}^2} + K\overline{\mathbf{V}\dot{\mathbf{V}}} = \frac{1}{R}V^2,$$

hence

$$\frac{1}{R} = K p_1 \theta_c$$

and equation (8) for the condenser current becomes

$$\mathbf{C} = K[\dot{\mathbf{V}} + p_1\theta_c \mathbf{V}] \quad \ldots \ldots \ldots \quad (11)$$

Now the torque acting on the moving coil is proportional to the average product $\overline{\mathbf{B}\mathbf{C}}$, and since λ and K are constants, we may write for this torque

$$\frac{\lambda}{K}\overline{\mathbf{B}\mathbf{C}} = \lambda\overline{\mathbf{B}[\dot{\mathbf{V}} + p_1\theta_c\mathbf{V}]} = \lambda\overline{\mathbf{B}\dot{\mathbf{V}}} + p_1\theta_c\lambda\overline{\mathbf{B}\mathbf{V}} \quad \ldots \quad (12)$$

But

$$\lambda \overline{\mathbf{B}\mathbf{V}} = \lambda \overline{\mathbf{B}(\mathbf{v} + \lambda \dot{\mathbf{B}})} = \lambda \overline{\mathbf{B}\mathbf{v}} + 0$$
$$= \lambda \mathrm{B} v \cos \theta_l,$$

also

$$v = \theta_r \mathrm{V} \quad \text{from (10)} \qquad \text{and} \quad \lambda \mathrm{B} p_2 = \mathrm{V}_m \quad \text{from (9)}.$$

It follows that

$$p_1 \theta_c \lambda \overline{\mathbf{B}\mathbf{V}} = \theta_c \theta_r \frac{p_1}{p_2} \frac{\mathrm{V}_m}{\mathrm{V}} \cos \theta_l \mathrm{V}^2$$
$$= \theta_c \theta_r \mathrm{V}^2 . \qquad (13)$$

since we are neglecting triple products of small quantities, and since

$$\frac{p_1}{p_2}, \quad \frac{\mathrm{V}_m}{\mathrm{V}}, \quad \text{and } \cos \theta_l,$$

each differ from unity by small quantities of the second or some higher order.

Now to find $\overline{\mathbf{B}\dot{\mathbf{V}}}$ we have from (5)

$$\lambda \overline{\mathbf{B}\dot{\mathbf{V}}} = -\lambda \overline{\dot{\mathbf{B}}\mathbf{V}} = -\overline{(\mathbf{V} - \mathbf{v})\mathbf{V}} = -\mathrm{V}^2 + \overline{\mathbf{v}\mathbf{V}}$$

on referring to Fig. 20, it will be seen that the angle between the vectors $\mathbf{v}$ and $\mathbf{V}$ is $\frac{\pi}{2} - (\theta_r + \theta_l)$, and owing to the smallness of the phase errors θ, the cosine of this angle is $\theta_r + \theta_l$, so that

$$\overline{\mathbf{v}\mathbf{V}} = (\theta_r + \theta_l) v \mathrm{V} = \theta_r (\theta_r + \theta_l) \mathrm{V}^2.$$

If now we substitute in (12) for $\overline{\mathbf{B}\dot{\mathbf{V}}}$ and $\overline{\mathbf{B}\mathbf{V}}$, we find the expression for the torque acting on the moving coil reduce to

$$\frac{\lambda}{\mathrm{K}} \overline{\mathbf{B}\mathbf{C}} = -\mathrm{V}^2 [1 - \theta_r(\theta_r + \theta_l) - \theta_r \theta_c] \quad . \quad . \quad . \quad . \quad (14)$$

or the torque is proportional to the mean square of the voltage multiplied by the factor

$$1 - \theta_r (\theta_r + \theta_l + \theta_c).$$

Hence if the scale of the instrument is graduated to read, not V^2, but V, the actual reading will differ from the true reading (for no copper drop θ_r) by an amount which bears to the latter the error ratio ϵ, where

$$\epsilon = \tfrac{1}{2} \theta_r (\theta_r + \theta_l + \theta_c).$$

In all practical cases the quantities θ can be made so small that their products can be neglected. Thus the errors due to hysteresis, condenser absorption, and copper drop can be made negligible in voltmeters of the type illustrated in Fig. 3.

3. The Phase Error due to Hysteresis.

The reduction of the hysteresis phase error is undoubtedly the greatest difficulty which has to be overcome before it is possible to construct good iron-cored instruments whose action is dependent upon the series form of electromagnet. The theory of this error has therefore been considered from more than one point of view.

In the first place, assume that the magnetic circuit has the same section everywhere, that g is the length of the air-gap, and l that of the iron path of the lines. If g is appreciable, the lines must spread at the gap, but for the present we assume all the lines to cross the gap by the shortest path. Let $m\,l = 1000\,g$, so that m is the ratio of the reluctance of the gap to that of the iron, on the assumption that $\mu = 1000$. It will be convenient to think of m in this way, though in what follows no assumption is made as to the constancy of μ. The quantity m so defined is a mere number independent of μ, and determined solely by the geometrical configuration of the iron core and the air-gap.

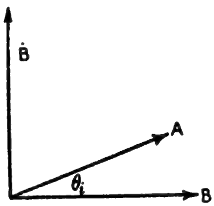


Fig. 21.

Let $\mathbf{B}$ be the flux density, and $\dot{\mathbf{B}}$ its time rate of change; and let $\mathbf{A}$ be the ampere-turns magnetising the electromagnet. We have to find the phase angle θ_ι separating the vectors $\mathbf{A}$ and $\mathbf{B}$ in Fig. 21. We have

$$\overline{\mathbf{A}\mathbf{B}} = \mathrm{A\,B}\cos\theta_\iota,$$

also the vectors $\mathbf{B}$ and $\dot{\mathbf{B}}$ are perpendicular whatever the wave-forms, since $\overline{\mathbf{B}\dot{\mathbf{B}}} = 0$. The three vectors are not necessarily in the same plane, but unless the wave-forms are extraordinary we can with all essential accuracy regard them as coplanar. Thus we can assume $\sin\theta_\iota$ equal to the cosine of the angle between the vectors $\mathbf{A}$ and $\dot{\mathbf{B}}$, or we have, since θ_ι is small,

$$\overline{\mathbf{A}\dot{\mathbf{B}}} = \mathrm{A}\dot{\mathrm{B}}\sin\theta_\iota = \theta_\iota\,\mathrm{A}\dot{\mathrm{B}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

But from the law of the magnetic circuit

$$\frac{4\pi}{10}\mathbf{A} = l\,\mathbf{H} + g\,\mathbf{H}_g = l\,\mathbf{H} + g\,\mathbf{B}$$

where $\mathbf{H}$ is the magnetic force in the iron, and $\mathbf{H}_g$ or $\mathbf{B}$ that in the gap. From the definition of m we have

$$m\,l = 1000\,g \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

or

$$\mathbf{A} = \frac{10\,l}{4\pi}\left[\mathbf{H} + \frac{m}{1000}\,\mathbf{B}\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

$$\therefore \quad \mathbf{A}\dot{\mathbf{B}} = \frac{10\,l}{4\pi}\left[\mathbf{H}\dot{\mathbf{B}} + \frac{m}{1000}\,\mathbf{B}\dot{\mathbf{B}}\right]$$

and on taking averages we have, since $\overline{\mathbf{B}\dot{\mathbf{B}}} = 0$,

$$\overline{\mathbf{A}\dot{\mathbf{B}}} = \frac{10\,l}{4\,\pi}\,\overline{\mathbf{H}\dot{\mathbf{B}}}$$

Now

$$\overline{\mathbf{H}\dot{\mathbf{B}}} = \frac{1}{T}\int_0^T \mathbf{H}\frac{d\mathbf{B}}{dt}\,dt = f\int \mathbf{H}\,d\mathbf{B}$$

where f is the current frequency, and $\int \mathbf{H}\,d\mathbf{B}$ denotes the area of the Ewing cycle of magnetism. Thus we have

$$\overline{\mathbf{A}\dot{\mathbf{B}}} = \frac{10\,l\,f}{4\,\pi}\int \mathbf{H}\,d\mathbf{B} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

$$= \theta_t\,\mathrm{A}\,\dot{\mathrm{B}} \qquad \text{by (16)}$$

$$= p\,\theta_t\,\mathrm{A}\,\mathrm{B}.$$

If we denote by A_1 and B_1 the *maximum* values of $\mathbf{A}$ and $\mathbf{B}$ respectively, we can put with sufficient accuracy—

$$p = 2\,\pi\,f, \qquad \mathrm{A} = \frac{1}{\sqrt{2}}\,\mathrm{A}_1, \qquad \mathrm{B} = \frac{1}{\sqrt{2}}\,\mathrm{B}_1,$$

although the true numerical constant for each of these equations depends somewhat on the wave-form.

$$\therefore \quad \frac{10\,l\,f}{4\,\pi}\int \mathbf{H}\,d\mathbf{B} = \pi\,f\,\theta_t\,\mathrm{A}_1\,\mathrm{B}_1 \quad . \quad . \quad . \quad . \quad (20)$$

Referring to (18) we have for maximum values

$$\mathrm{A}_1 = \frac{10\,l}{4\,\pi}\left(\frac{1}{\mu} + \frac{m}{1000}\right)\mathrm{B}_1 = \frac{10\,l}{4\,\pi}\,\frac{m'}{1000}\,\mathrm{B}_1 \quad . \quad . \quad . \quad (21)$$

where

$$m' = m + \frac{1000}{\mu} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

and is essentially the same as m, since μ is greater than 1000 usually, and m must be a large number.

From (20) and (21) we get, on simplifying,

$$\theta_t = \frac{1}{\pi\,m'}\,\frac{10^3\int \mathrm{H}\,d\mathrm{B}}{\mathrm{B}_1^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

which is the formula for the hysteresis phase error. m' is the ratio of the reluctance of the whole circuit to that of the iron path calculated on the assumption that $\mu = 1000$.

We have assumed that the section of the flux at the air-gap is the same as that of the core. If, owing either to the spreading of the lines at the gap, or to extended pole-pieces, the flux section at the gap is greater than the core section, the value of m' must be correspondingly

reduced, and the uncertainty attaching to this value owing to the unknown distribution of the lines makes it impossible to establish an accurate formula for θ_t. It will be seen from (17), (22), and (23) that in order to reduce θ_t we must make m' large by making the ratio g to l as great as possible. The value of the factor

$$\frac{10^3 \int H\,d\,B}{B_1^2}$$

depends simply on the quality of the iron, and the value of B_1 used in working the electromagnet. It is a quantity which for good iron, and for ordinary flux densities over 1,000 C.G.S., will be found, on reference to Ewing's researches and making the necessary calculations from the results given, to lie as a rule between the limits 0·5 and 1·5. The value of θ_t thus mainly depends upon the effective value of m', and to make θ_t less than 1 per cent. of a radian m' should be about 50. If we allow for some spreading of lines at the gap and a moderate leakage factor, this implies that the length of the air-gap should be at least one-tenth of the length of the iron part of the circuit.

We may regard the question from another point of view, as follows:—

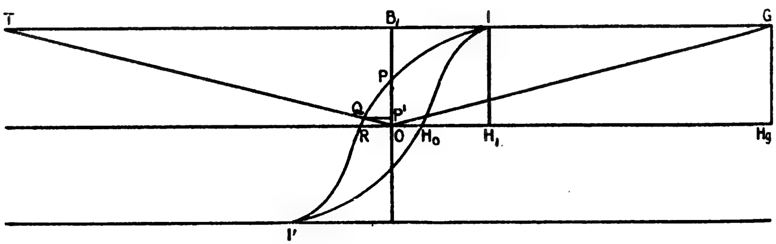


FIG. 22.

Let the B H curve of the iron for the cycle considered be $H_0\,I\,R\,I'$ in Fig. 22, where

$$\begin{aligned} O\,B_1 &= B_1 \quad \text{the maximum value of } B, \\ O\,H_1 &= H_1 \quad \text{,, \quad ,, \quad ,, \quad } H, \\ O\,H_0 &= H_0 \quad \text{the coercive force}, \\ O\,P &= \rho\,B_1 \text{ the remanent magnetism}, \\ \text{and} \quad & \rho \text{ is the remanence ratio, or remanence.} \end{aligned}$$

Now from (18) it will be seen that we can regard H_1 as a measure of the magnetising current required to produce the flux density B_1 in the iron, and $m\,B_1/1000$ or $m\,\mu\,H_1/1000$ as a measure of the current needed to magnetise the air-gap to the same flux density. If in the figure we draw a line O G such that

$$\frac{B_1\,G}{B_1\,I} = \frac{m\,\mu}{1000}$$

it follows from a construction due to Dr. J. Hopkinson, and quoted and extended by Ewing,* that the curve connecting the flux with the

* *Magnetic Induction in Iron*, p. 267.

magnetising current for the entire magnetic circuit will be represented by the figure obtained on shearing the Ewing cycle $H_0 I R$ parallel to the axis of H through a distance which for any value of B is the corresponding abscissæ of the line O G. The intersection of $O B_1$ with the curve will move from P to P′, where P′ is the sheared position of Q, a point obtained from the intersection of the curve with O T, the image of the line O G with regard to the line $O B_1$. The area of the sheared loop will be the same as that of the normal Ewing cycle, and each will represent the loss of energy in the iron. The sheared figure will be bounded by smooth lines of inappreciable curvature when the ratio $B_1 G : B_1 I$, or $m \mu/1000$, is large. The new value for the remanence ratio ρ will be given by

$$\rho = \frac{O P'}{O B_1} = \frac{Q P'}{T B_1} = \frac{O R}{B_1 T} = \frac{H_0}{B_1 G}$$

since the points Q and R will be almost coincident under the circumstances assumed.

Now

$$(B_1 G) = \frac{m \mu}{1000} (B_1 I) = \frac{m}{1000} \mu H_1 = \frac{m B_1}{1000}$$

and we thus have

$$\frac{H_0}{\rho} = \frac{m B_1}{1000} \qquad \text{(24)}$$

Substituting in (23) we get

$$\theta_t = \frac{\rho}{\pi} \frac{m}{m'} \frac{\int H\,d B}{H_0 B_1} \qquad \text{(25)}$$

where ρ is a quantity which can be experimentally measured for any magnetic circuit, and is its remanence ratio for a Ewing cycle of maximum flux density B_1.

The ratio

$$\frac{\int H\,d B}{H_0 B_1}$$

is a quantity which, when calculated from the experimental results obtained in Ewing's researches, is found to be fairly constant for large variations of B_1. It depends upon the quality of the iron, and it is remarkable that for any particular kind of iron it appears to be accurately represented by a linear function of B_1 over a large range. Thus from Ewing's measurements on a specimen of transformer iron the calculated value of this quantity is 3·0 at $B_1 = 1000$, and 4·0 at $B_1 = 9200$. The linear relation corresponding with these values very closely represents the quantity for the whole range of B_1 covered by Ewing's tests on the specimen in question, *i e.*, from $B_1 = 1000$ to $B_1 = 13{,}000$.

The coefficient of ρ in (25) is a number differing very little from unity, since m is essentially the same as m', and the remaining factor

$$\frac{1}{\pi} \frac{\int H\,d B}{H_0 B_1}$$

only seems to differ from unity by a few per cent.

Thus for ordinary ranges of B_1 and for usual kinds of iron the hysteresis phase error θ_t is very approximately the same as the remanence ratio ρ of the magnetic circuit. But there is some uncertainty about the matter for low flux densities B_1, since Ewing's researches do not sufficiently cover ranges of B_1 below 1000 C.G.S. units. The same conclusion may, however, be arrived at by the following method :—

Let the Ewing loop representing the relation between the total magnetic flux $\mathbf{N}$ and the corresponding magnetising current $\mathbf{A}$ be

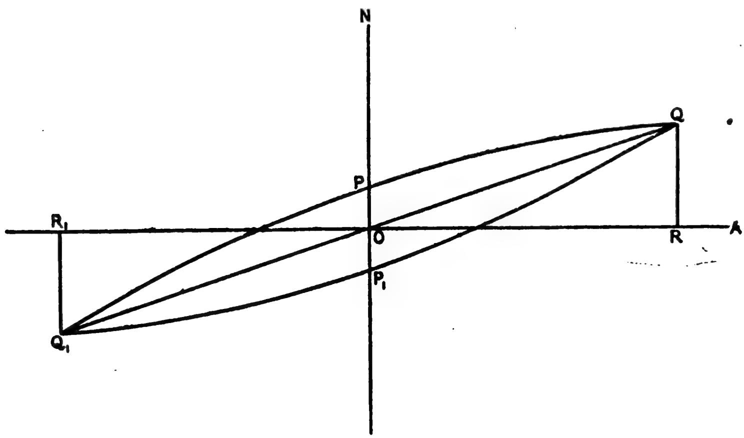


FIG. 23.

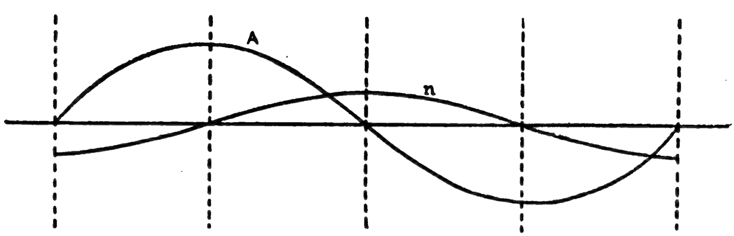


FIG. 24.

QPQ_1P_1 in Fig. 23; QR and OR representing the maximum values of $\mathbf{N}$ and $\mathbf{A}$ respectively.

We may put

$$\mathbf{N} = L\mathbf{A} + \mathbf{n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

where L is a constant such that $L\mathbf{A}$ is the ordinate of OQ for the abscissa $\mathbf{A}$, and $\mathbf{n}$ is the excess of $\mathbf{N}$ above the ordinate. The value of $\mathbf{n}$ is negative while the current is increasing, and positive while it is decreasing.

The effect of the air-gap will be to reduce the remanence ratio

ρ or OP/QR to a very small quantity. The lines Q_1PQ and Q_1P_1Q will have such small curvature that they will be essentially circular arcs. The maximum values of $\mathbf{n}$ will occur when $\mathbf{A}$ is zero or very nearly zero, while $\mathbf{n}$ will be zero when $\mathbf{A}$ reaches either of its extreme values.

It follows that the mean product $\overline{\mathbf{A}\mathbf{n}}$ will be very small compared with the product $A n$ of the magnitudes of these quantities, or we may put

$$\overline{\mathbf{A}\mathbf{n}} = A n e \quad \dots \dots \dots \dots \quad (27)$$

where e is a very small fraction.

In fact, if the time curves of $\mathbf{A}$ and $\mathbf{n}$ be plotted as in Fig. 24, the corresponding ordinates of these curves are rigidly related in a manner quite independent of frequency and almost so of wave-form, and if $\mathbf{A}$ varies according to $\sin pt$ the curve for $\mathbf{n}$ will closely follow the law $\cos pt$. The vector triangle corresponding with (26) will be essentially right-angled, with the vector $\mathbf{N}$ as hypothenuse. The phase angle θ_t between $\mathbf{N}$ and $\mathbf{A}$ will be such that

$$\sin \theta_t = \frac{n}{N} \quad \dots \dots \dots \dots \quad (28)$$

But the ratio n/N will be practically the same as that of the maximum values of these quantities or OP/QR, which is ρ the remanence ratio, so that when θ_t is small (28) reduces to

$$\theta_t = \rho \text{ approximately} \quad \dots \dots \dots \quad (29)$$

Indeed, if we multiply (26) by $\mathbf{A}$ and take means, we have with the aid of (27)

$$\overline{\mathbf{N}\mathbf{A}} = L\overline{\mathbf{A}^2} + \overline{\mathbf{A}\mathbf{n}} = L A^2 + A n e \quad \dots \dots \quad (30)$$

also by squaring (26) we have

$$\mathbf{N}^2 = L^2 \mathbf{A}^2 + 2 L \mathbf{A}\mathbf{n} + \mathbf{n}^2,$$

and on taking means we get

$$N^2 = L^2 A^2 + 2 L A n e + n^2; \quad \dots \dots \quad (31)$$

$$\therefore \quad \cos^2 \theta_t = \frac{(\overline{\mathbf{N}\mathbf{A}})^2}{N^2 A^2} = \frac{L^2 A^4 + 2 e L A^3 n + A^2 n^2 e^2}{L^2 A^4 + 2 e L A^3 n + n^2 A^2},$$

or

$$1 - \cos^2 \theta_t = \frac{n^2 A^2 (1 - e^2)}{N^2 A^2} = \frac{n^2}{N^2}(1 - e^2).$$

For small values of θ_t this reduces to

$$\theta_t = \frac{n}{N}\left(1 - \tfrac{1}{2} e^2\right) \quad \dots \dots \dots \dots \quad (32)$$

and since e is a very small fraction, this relation is equivalent to (28) and (29).

ORIGINAL COMMUNICATION.

NOTE ON THE USE OF THE BOLOMETER AS A DETECTOR OF ELECTRIC WAVES.

By Lieutenant C. TISSOT, Brest.

It is several years ago since I carried out a number of experiments in all respects analogous to those of Mr. Duddell, by taking observations with a sensitive thermo-detector placed in circuit with the receiving aerial. The apparatus which I used in my experiments is a kind of bolometer which enables one to record the variations of resistance of a very fine metal wire produced by very small changes in temperature in a similar way to the arrangement of Langley.* The principal object of these experiments was the investigation of the conditions of resonance in the aerial systems, but occasionally they resulted in my observing phenomena identical with those which have been pointed out by Messrs. Duddell and Taylor. It may therefore be of interest to describe my unpretentious experiments, and in so doing I propose to allude only to those particular points which appear to be common to both series of investigations, and not to deal either with questions of resonance, frequency, or damping.

The principle of Langley's bolometer is well known. Two fine metal wires are inserted respectively in the two arms of a Wheatstone bridge. A variation in temperature of one of the wires produces a variation in its resistance which is indicated by the bridge galvanometer; the bridge having been previously balanced.

In applying the bolometer to the detection of electric waves it is necessary to ensure the complete heat isolation of the bolometric arms, and on the other hand to localise the action of the waves in one arm only.

To effect this the arms, which are straight and very short—1·5 cm. of 10 μ diameter platinum wire, in the most sensitive models—are brought very near to one another within the same enclosure.

In one of the types employed these arms are in vacuo. The case in which they are contained is made as small as possible and is enclosed in two successive coverings of silver-plated brass, between which is a very thin air space. The whole is immersed in a small vessel filled with water. In another model the heat isolation is obtained in a more simple manner by means of a Dewar vacuum vessel.

* *Comptes Rendus*, vol. 136, p. 361, 1903; vol. 137, p. 846, 1903. *Journal de Physique*, Ser. 4, vol. 3, p. 524, 1904

According to the kind of measurements for which the apparatus is intended, two different methods are employed for localising the effect of the wave. In one of these methods, similar to that employed by

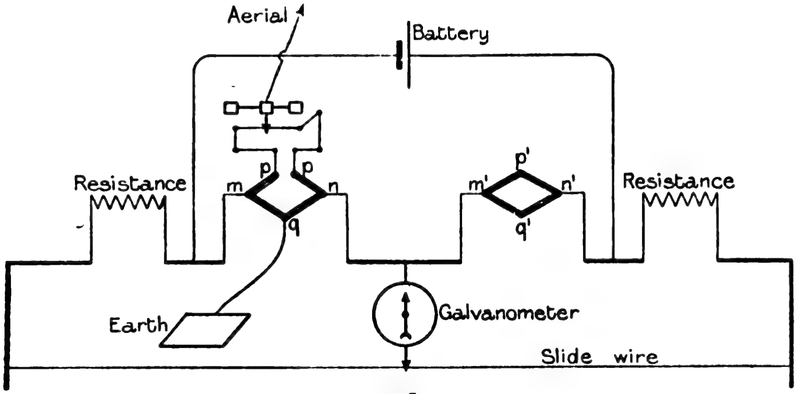


FIG. 1.

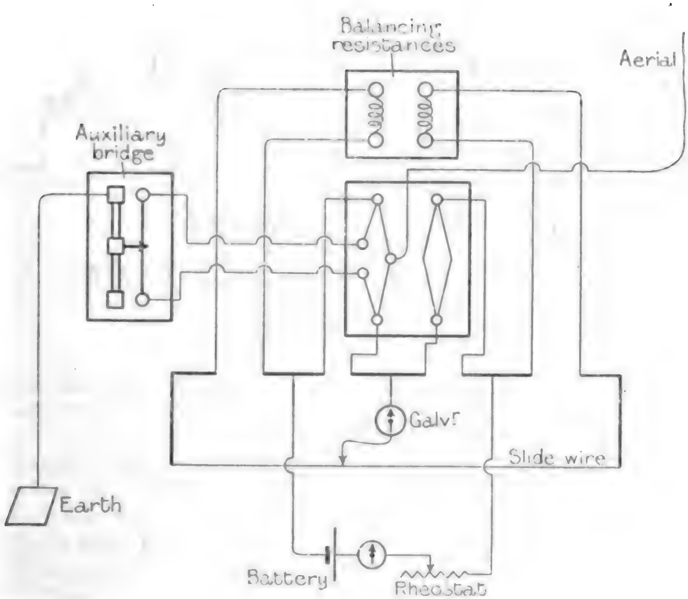


FIG. 2.

Rubens, each arm of the bolometer is formed by four exactly equal pieces of wire arranged in the form of a bridge (Figs. 1 and 2).

The balancing resistances of the bridge are either of German silver or platinoid, and are immersed in petroleum. The balancing of the main bridge is performed by means of a slide wire of large diameter.

The aerial and the earth connection are attached at *pp* and *q* to that diagonal which is not in the circuit of the main bridge.

The apparatus can be calibrated direct by a continuous current and can be used as a wattmeter (the resistance being known and the self-induction negligible). The method employed for taking the measurements consists in the observation of the permanent deflection of the galvanometer of the main bridge under the action of the waves received during a suitable time. The aerial and the earth are removed, and there is connected in their place a source of direct current capable of supplying the required current to the bolometric bridge *m n p q*, so as to produce the same deflection of the galvanometer of the main bridge.

Since it is necessary that the unbalancing of the main bridge shall be solely due to the heat developed in the auxiliary bridge *m n p q*, an external means of adjustment (a kind of slide wire) was added to the bolometric bridge in order to be able to realise exactly the desired

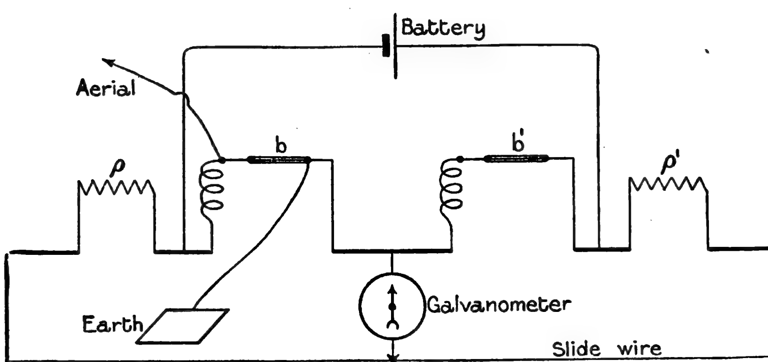


FIG. 3.

conditions. These are obtained when the galvanometer deflects in the same direction and exactly to the same amount, on reversing the direct current in the auxiliary bridge.

The other method of localising the effect of the waves consists in inserting between the bolometric arms, each of which are formed of a single piece of wire, suitable ironless choking coils, of dimensions previously determined by experiment. The aerial and earth are then connected as shown in Fig. 3. The sensibility of these arrangements depends, of course, upon that of the galvanometer employed. For moderate degrees of sensibility a d'Arsonval dead-beat galvanometer was used. The apparatus is then suitable for use on board ship. Where extreme sensitiveness was required I employed a moving needle galvanometer (Thomson's type) with two parallel vertical needles, the resistance of the galvanometer being chosen equal to that of each of the bridge arms. I was thus able to obtain deflections of about

10 millimetres with an effective current of 100 micro-amperes (scale at one metre distance).

The arrangement of the transmitter and receiver is shown in Fig. 4.

If the length of the transmitting aerial A is left constant and that of the receiving aerial B be varied progressively, it will be noted that the deflections of the bolometer reach a maximum for a certain length of B. The aerial system A B are then in resonance and have the same natural period.

When the aerials A and B have the same shape, for instance both being either simple wires or both consisting of four parallel wires, it will be found that the resonance always occurs when the lengths are equal whatever may be the general curvature or inclination of the aerials. The measurements given refer to systems in resonance.

1. Influence of the Resistance of the Measuring Instrument.

By varying the value of a non-inductive resistance arranged in series with the instrument in the receiving aerial, I found that there

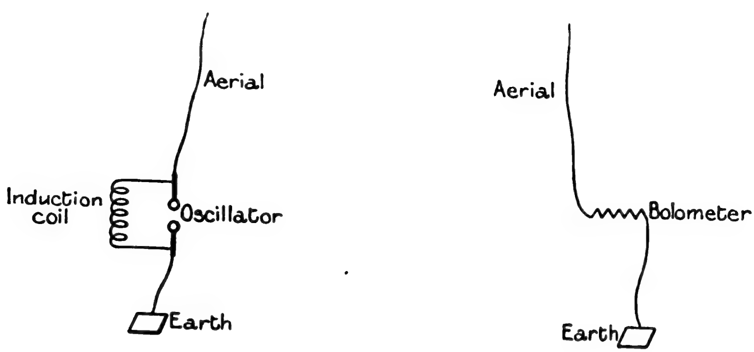


Fig. 4.

was a best value for the resistance from the point of view of the energy absorbed. In my experiments this value appeared to lie between 50 and 60 ohms. In fact, of three similar instruments the respective resistances of which were 15, 42, and 82 ohms, it was the 42-ohm instrument which absorbed most energy and therefore gave the best results.

I am of opinion that the value of the "best" resistance depends upon the aerial employed, and that the most favourable conditions are approximately reached when the resistance of the instrument is equal to the resistance of emission. By "resistance of emission" I mean that amount of resistance which, assuming no loss of energy by radiation, the aerial should have, in order that the damping of the oscillations by the frictional resistance may be equal to that due to radiation only.

2. Variation of the Received Energy with Distance.

At first I only carried out tests at distances between 1 to 9 kilometres.* But within these restricted limits, and when working with aerials tuned in such a manner as to reduce the influence of the harmonics, I found that the effective value of the current in the receiving aerial is inversely proportional to the distance. The energy received, which is represented by the product ri^2, varies, therefore, inversely as the square of the distance. At a later date I was able to extend these measurements to a distance of 40 kilometres, and I obtained absolute confirmation of the law which Mr. Duddell has so well demonstrated over longer distances.

3. Influence of the Earth.

I also carried out a great number of measurements with various methods of earthing, both at the transmitting and receiving stations. Without entering into the details of these experiments I may say that with regard to the influence of the surface of the earth capacity I arrived at the same general conclusions as Mr. Duddell. I observed particularly that the "earth" obtainable on board ship by connecting to the hull is very much better than that which one gets on land by means of plates buried in the ground. I believe, however, that I have established the fact, contrary to the opinion expressed by Mr. Duddell, that the ground when damp makes a better earth than when dry. These conclusions are rendered apparent not only by direct measurements of the energy by means of the bolometer, but by the data resulting from the study of the damping.

4. Number of Interruptions.

My experimental observations also showed that if the number of interruptions is made to vary from n to n' per second, the effective value of the current received by the aerial varies in the ratio of $\sqrt{n}$ to $\sqrt{n'}$. This result, which appears in accord with the observations of Duddell and Taylor, is readily capable of interpretation by reasoning as follows: Let

I denote the reading on a hot wire ammeter put in series at the bottom of the transmitting wire.
A = the amplitude of the current in the aerial.
T = the period.
γ = the decrement of the oscillation.
n = the number of interruptions, that is of wave trains per second.

By a simple integration we then obtain for the fundamental wave—

$$I^2 = n \frac{A^2}{4\gamma} \cdot \frac{4\pi^2}{4\pi^2 + \gamma^2} \cdot T.$$

* *Comptes Rendus*, vol. 138, p. 680.

Since the factor $\frac{4\pi^2}{4\pi^2+\gamma^2}$ is almost equal to unity, it is clear that the energy transmitted by a single wave train, which is proportional to A^2, is given by a relation of the form $W_e = K A^2 = K' \frac{I^2}{n}$ (K and K′ being constants). In the same manner the energy received for a single wave train is easy to compute, if one assumes that the detector completely absorbs this energy. If an effective current i is obtained with n interruptions, that is with n trains per second, then the equation $W = \frac{\rho i^2}{n}$ expresses the energy received for a single wave train, ρ being the resistance of the measuring instrument (in this case the bolometer), when the number of interruptions varies from n to n', i varies from i to i', and $\frac{i'^2}{i^2} = \frac{n'}{n}$, whence $\frac{i'}{i} = \frac{\sqrt{n'}}{\sqrt{n}}$

5. Numerical Value of the Energy brought into Play.

These considerations enable us to compare the values we have obtained with those obtained by Mr. Duddell. The direct system of excitation was used, the transmitting aerial being connected to one spark ball of the oscillator, the other ball being connected to earth. The transmitting and receiving aerials were identical, and were consequently in resonance without any added self-induction. Each of the aerials consisted of four parallel wires at a distance apart of one metre and having a total length of 55 metres from the extreme summit to the ground.

With 26 interruptions per second the hot wire ammeter in the transmitting aerial shows 2·8 effective amperes. With a bolometer inserted between the receiving aerial and the earth the following values were obtained :—

Distance D in Kilometres.	Current i in the Receiver in Micro-amperes.	Product $i \times$ D.
1·150	8,290	9,550
8·000	1,180	9,450
40·000	235	9,400

Although a slight regular decrease is apparent in the product $i \times$ D, it may be nevertheless regarded as constant. Consequently under the same conditions at the transmitter the value of the current at 48 kilometres—that is, at 30 miles—would be 195 micro-amperes.

The values obtained appear, therefore, to be somewhat higher than those of Duddell and Taylor, since they refer in this case to 26 wave

trains. But the conditions of the experiments are not altogether the same, seeing that my observations refer to a system which was excited by direct coupling.

I believe, moreover, that the resonance was somewhat sharper in my experiments, because the proper frequency of the aerials as arranged was strictly the same. In any case I venture to hope that it may be of interest to the members of the Institution to place on record these results.

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 36. 1906. No. 178.

Proceedings of the Four Hundred and Thirty-eighth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 22, 1906—Mr. JOHN GAVEY, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on March 8, 1906, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members—

Patrick Hamilton. | Edward John Neachell.
Edward Ernest Tasker.

From the class of Associates to that of Associate Members—

James McLachlan. Charles Ernest Newton.

From the class of Students to that of Associate Members—

F. Tozer Chapman. William Allwood Dutton.

Messrs. C. W. Fourniss and A. Schneider were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

William Baxter.
William Street Foale.
William Shawhill Johnston.
Henry Labour.
Douglas Hunter Laidlaw.
Edgar Lunn.
Melville John Hastings Pockson
George Gladman Sarney.
William Alan Walker.

As Associate.

Stanislaus George Reilly.

As Students.

Cecil A. Abbott.
James Miller Barlas.
John S. Blackmore.
Benjamin Francis Cauter.
Charles Wellington Crocker.
Luiz Antonio Maravilhas.
Thomas Joseph Monaghan.
Andrew George Stamatopoulos.
George Herbert Stevens.
Albert Arnold Zapp.

Donations to the *Library* were announced as having been received since the last meeting from the Board of Education, Messrs. A. Constable & Co., Ltd., The Engineering Standards Committee, H. R. Kempe, T. Commerford Martin, R. H. Smith, H. G. Solomon, The Victorian Institute of Surveyors, Whittaker & Co.; to the *Building Fund* from J. Gavey; and to the *Benevolent Fund* from Messrs. J. Gavey, S. G. C. Russell, R. J. Wallis-Jones. The President also announced that the Executive Committee of the Electrical Exhibition, 1905, had granted out of the profit of that Exhibition a special donation of £350 to the Benevolent Fund. The thanks of the meeting were duly accorded to all of the donors.

The following papers were read and discussed, and the meeting adjourned at 9.30 p.m. :—

ELECTRICAL EQUIPMENT OF THE ABERDARE COLLIERIES OF THE POWELL DUFFRYN COMPANY.

By CHARLES P. SPARKS, Member.

(*Paper read March* 22, 1906.)

The group of collieries dealt with in this paper are situated 20 miles north-west of Cardiff; they have been worked by the Powell Duffryn Company since 1864, and are now raising 1¼ million tons of coal out of the company's output of 2¾ million tons per annum.

Before the present scheme was put in hand six of the nine pits in this valley had isolated direct-current plants generating at 200 or 400 volts for lighting and power purposes.

In place of extending these plants for the more general use of electric power, it was decided to erect a power station to supply the whole of the company's pits in the Aberdare Valley, to obtain the advantage of a higher load factor by concentrating the generating plant in one power house, in place of having plant, together with reserves, capable of dealing with the maximum power required at each pit, the direct result being to lower the capital and generating costs, due to the decreased amount of generating plant required, the lower cost per k.w., and greater economy of the larger units erected at a single power station.

The district to be served was eight square miles in area, some points being *four* miles from the proposed power station; and as a considerable demand for power might develop at any point in this area, it was decided to use the 3-phase system at 50 periods, 3,000 volts, with overhead transmission lines, the existing D.C. motors being utilised, grouping nineteen motors of 210 B.H.P. at one pit and driving them from the 3-phase system by a motor generator supplied at 3,000 volts.

Electric power is now being supplied to seven of the pits from a power station which has been erected close to the coal-washery, which is situated fairly centrally to the company's property as shown in Fig. 1.

The scheme was projected in 1903, before the issue of the Home Office Regulations for the use of electricity in mines, and a contract for the whole work given to the Electrical Company in the autumn of the same year. The power station was started and the first motors put to work in May, 1905.

Owing to the nature of the business the drives could only be gradually transferred from steam to electric, and at the end of 1905 some 4,600 B.H.P. of motors were at work out of a total of 6,000.

The total H.P. at present in use at these collieries amounts to 12,170, and while the most uneconomical drives, amounting to over one-third of the total, have been converted from steam to electric driving, resulting during December, 1905, in putting 25 Lancashire boilers out of use, displacing the boiler plant entirely at five points, 32 Lancashire boilers 30 ft. by 8 ft., or their equivalent, still remain driving the balance of 7,570 H.P. Now that the power station has been started there is little doubt that, as occasion arises, a large part of the remaining steam plant will be superseded by electric driving.

The present records show the colliery requirements to average 1,000 units per annum per B.H.P. erected, with a load factor on the power station of 37 per cent. Were the whole of the driving electric, the output of the power station would be about 12 million units per annum, the load factor on the station being between 40 and 50 per cent., the latter figure being reached if pumping was confined to the hours when the haulages were not at work, ten units being required for all power purposes per ton of coal raised with the present output of 1¼ million tons per annum.

When the cost of power is compared with the labour cost incurred in winning a ton of coal, the importance of increasing the application of power makes the use of electricity a matter of interest to all colliery owners, as no other means of power transmission is available that has equal flexibility in distribution or is so well adapted to every form of drive above and below ground.

The capital outlay necessary for the change has been an important factor in deterring changes on a large scale, but as the cost of electric machinery has been largely reduced in recent years there is every reason to believe that rapid progress will now be made in the conversion of collieries to electric driving.

Power Station.

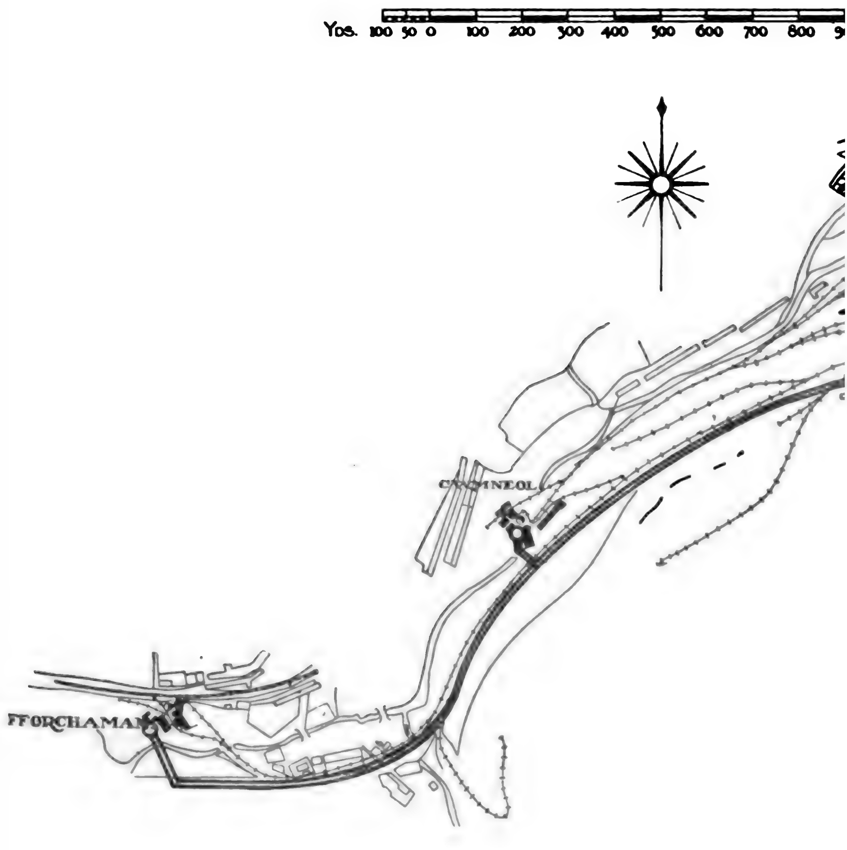
The power station is equipped to deal with an average load of 1,500 k.w., this demand being met either by a 1,500-k.w. or two 750-k.w. sets during the day, and one 750-k.w. set during the night and on Sundays.

The alternators, one of 2,000 and two of 1,000 k.v.a., are 3-phase star-connected (with neutral earthed). The regulation of these machines is 6 per cent. on non-inductive and 16 per cent. on inductive load, 0·75 power factor. The field magnets are carried by the engine flywheel, the machines being mounted between the cylinders of slow-speed engines; excitation for each set is provided by a rope-driven exciter (110 volts).

The engines are horizontal, cross compound, jet condensing, made by Yates & Thom, of Blackburn. They are governed on both high and low pressure cylinders so as to carry momentary overloads of 50 per cent. The air pumps on the larger set are of the Edwards type, driven from the tail-rod of the high pressure cylinder.

The parallel running of these sets is satisfactory under all con-

THE POWELL DUFF
STEAM COAL COMP
POWER DISTRIBUTION



ditions, while the steady pressure of supply gives satisfactory results in starting and running the largest motors under heavy overloads without interference with the general good working of the system.

The leading details of these sets are given in the following Table :—

TABLE I.

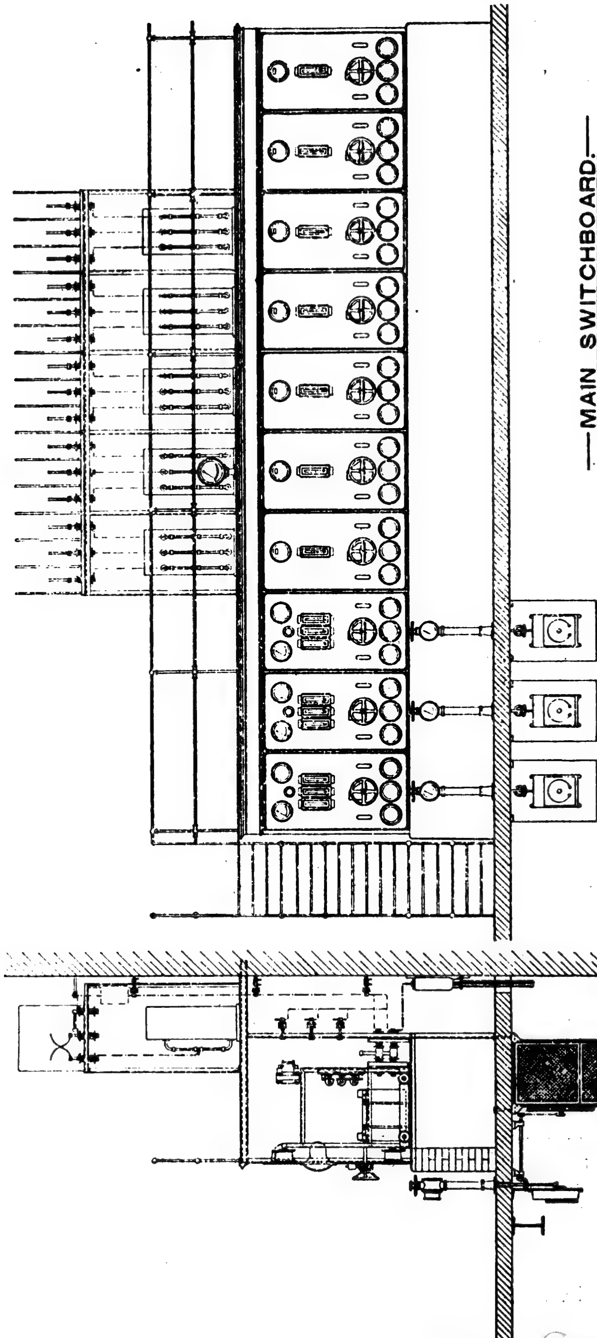
Alternator	1,500 k.w.	750 k.w.
Output...	2,000 k.v.a.	1,000 k.v.a.
Pressure	3,300 volts	3,300 volts
Frequency	50	50
Speed	83	94
Slots per pole and phase	2	2
Engine—		
Steam pressure, lbs. per square inch...	120	120
Superheat	60° F.	60° F.
Diameter of cylinders—		
H.P.	35 in.	26 in.
L.P....	66 in.	47 in.
Stroke...	54 in.	42 in.
Diameter of piston-rod	8 in.	5 in.
Diameter of crank shaft bearings	22 in.	17 in.
Length of bearings...	38 in.	30 in.
Length of connecting-rod	12 ft.	9 ft. 6 in.
Flywheel effect in foot-tons ...	5,500	2,200
Floor space occupied by combined set, in square feet...	988	720
Height of alternator above floor line	17 ft.	13 ft.

Steam is supplied from Babcock & Wilcox boilers, each having a grate area of 49 sq. ft., heating surface 3,080 sq. ft., with 350 sq. ft. of superheating surface, five boilers being used at time of maximum load.

The boilers are set in pairs and are hand-fired with unwashed small coal, the fuel being delivered from overhead bunkers filled by a bucket conveyor. The feed is heated by a Green's economiser. Water for condensation is obtained from a reservoir directly connected with the river.

The switchboard is of the carriage type (Fig. 2).

The board is of cellular construction with the bus-bars running along the back in a separate chamber, from which contacts project into each division. The whole of the switch-gear, instruments, and transformers for each panel are mounted on a carriage which can be withdrawn as a whole on to a trolley should any adjustment become necessary. With the panels in position the exterior of the board consists of brick or earthed metal work. This system is a safe one for the employees, as no adjustment can be made on the working parts of the switch-gear unless it is dead, the panel being only movable when the main switch is in the "off" position.



MAIN SWITCHBOARD
AT THE ABERAMAN POWER STATION
MESSRS. THE POWELL DUFFRYN STEAM COAL CO.

FIG. 2.

Scale 1 : 80

0 5 10 ft.

All panels are equipped with 3-phase oil break switches, fitted with overload relays, which actuate solenoids, worked by D.C. (supplied from a small battery charged from the exciters), the machine panels having in addition reverse current cut-outs; synchronising is effected by a synchroscope. The machine panels have ammeter, wattmeter, and voltmeter; the circuits, ammeters and watt-hour-meters. The top of the board is enclosed and is used as a platform to obtain access to the lightning arresters and their resistances. These are protected by divisions, but are not enclosed.

The maximum demand reached during 1905 has been 1,400 k.w., momentary demands reaching 1,750 k.w., this demand on the power station being one-third of that required to drive all the motors erected if they were all run simultaneously at maximum load.

The output of the power station is now at the rate of 4½ million units per annum, so that the load factor of the station when the original equipment of motors is completed will lie between 35 and 40 per cent., and when the percentage of pumps and fans driven electrically is increased, and the pumping confined as far as possible to the night, a load factor of over 40 per cent. will be reached.

Tests of the power station show a fuel consumption with unwashed small coal having a calorific value of 13,000 B.Th.U., with the sets operating at full load, of 2·7 lbs. for the 1,500, and 3 lbs. with the 750-k.w. sets, the weekly coal figure per unit delivered to the transmission lines averaging 3¾ lbs. of the above coal, with an output varying between 87,500 and 92,000 units per week.

Transmission Lines.

The transmission lines are designed to supply 6,000 B.H.P. of motors, based on a motor efficiency of 87 per cent., power factor 75 per cent., with a maximum drop of 10 per cent. in pressure with 70 per cent. of the motors working at full load simultaneously at any individual point.

TABLE II.

	Distance from Power Station in yds.	Cross Section Feeder. Sq. inches.	B.H.P. of Motors Supplied, Dec., 1905.
Lower Duffryn	1,870	·08	1,131
Abercwmboi	1,930	·04	205
Old Duffryn and Lletty Shenkin	620	·11	561
Upper Lletty Shenkin	1,268	·04	441
Aberaman	1,325	2 × ·15	960
Cwmneol	2,715	2 × ·15	316
Fforchaman	3,770	2 × ·15	821
Treaman	—	—	—
George	—	—	—
Washery (Power Station) ...	—	—	105
			4,540

Table II. gives the distance between pits and the power station, the cross-section of each feeder, and the B.H.P. of motors now in use, the greatest distance to a centre of distribution (above ground) from the

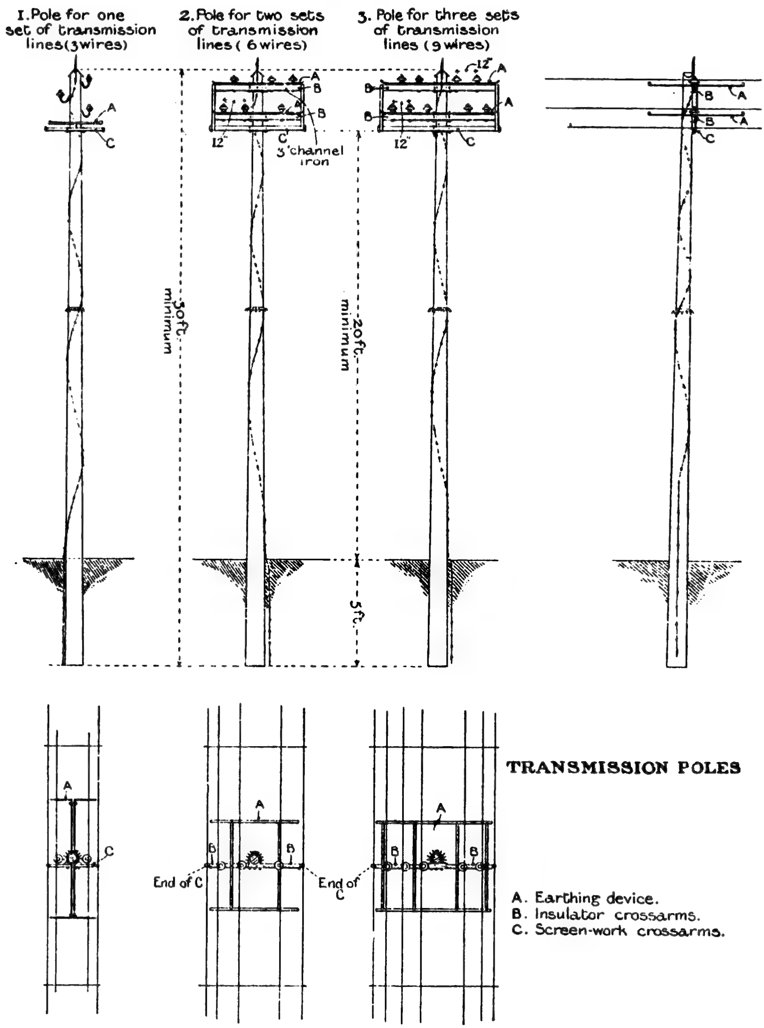


FIG. 3.

power station being $2\frac{1}{4}$ miles. As the conductors radiate three-quarters of a mile beyond this point, the longest transmission is 3 miles.

In addition the lighting load above and below ground amounts to 125 k.w.

The overhead transmission lines are bare hard-drawn copper conductors, wires up to 0·042 sq. in. (4 S.W.G.) being solid, any wires over this size being stranded. Fig. 3 shows the general construction of the transmission line. The wires are supported on wooden poles, except at points of special strain, where lattice steel poles are used.

The poles are creosoted, and average 33 ft. long by 7 in. in diameter at the top; 6 ft. to 7 ft. are embedded in the earth, and where the foundation is doubtful they are set in concrete. The poles are erected an

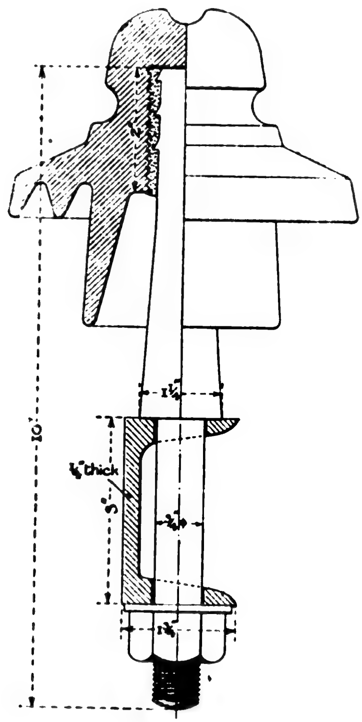


FIG. 4.

average of 40 yds. apart, the maximum distance in straight runs not exceeding 45 yds.

The wires are supported on porcelain insulators mounted on wrought-iron supports (Fig. 4). The insulators are set at 12 in. centres horizontally, and 18 in. vertically, the wires being carried 20 ft. from the ground level.

Guard-netting is erected below the transmission lines at all points where existing wires are crossed, or in the vicinity of the colliery premises where there is traffic. This guard-netting consists of two steel wires, $\frac{5}{16}$ in. in diameter, stretched below the transmission wires with transverse $\frac{1}{4}$ in. diameter wires every 6 ft., the ends of the trans-

verse wires being turned up to insure any broken wire being caught by the netting. Where guard-netting is not used, steel catchers are fitted at each pole to insure a broken wire striking the catcher thus becoming earthed. To prevent any one climbing the poles they have barbed wire spiralled round them, and are further protected by having a ring fitted with spikes fixed on each pole 10 ft. from the ground. At one point where the wires cross a number of telegraph lines on a public road, the transmission wires are carried through a lattice bridge, provision being made for twelve conductors, of which six are erected at present. The total length of the pole route is 8¾ miles, on which 33 miles of wire have so far been erected.

In addition to the transmission wires, the poles carry telephone wires connecting the power station and the various substations; these wires are crossed every 200 yds., to minimise induction.

The whole of the overhead wires are erected on colliery property, except where public roads are crossed.

SUBSTATIONS.

The substations are either separate buildings or rooms to which ordinary employees have no access. Each substation is fed from the power station by one or more H.P. feeders, as shown in Fig. 5, the feeders being protected at each end by lightning arresters.

Before connection to the substation bus-bars the incoming feeders are controlled by oil break switches and by fuses in the case of substations fed by two feeders.

The substation bus-bars branch to:—

(1) 3,000-volt substations below ground, connected by armoured cables.

(2) 3,000-volt motors connected by overhead distributors.

(3) Three-phase transformers reducing the pressure to 500-volts (for motors below 50 H.P.).

(4) Single-phase 110-volt lighting transformers.

Each high-pressure panel for outgoing feeders or transformers is equipped with oil break switch, enclosed fuse, and series ammeter transformer, so that the demands on the individual circuits can be checked. The back of each panel is only accessible when the controlling switch is in the "off" position.

The low-pressure circuits have 3-pole enclosed fuses, combined with switches, arranged so that all exposed metal is dead when the switch is opened for the renewal of fuses. Each substation is provided with one voltmeter for each pressure and two ammeters.

Underground Substations.—The general arrangement is the same as those above ground, but in this case each panel of the switch-gear is placed in a separate brick compartment, closed by a lock-up metal case, the whole switchboard being independently roofed in. These substations are placed close to the downcast shaft to admit of their being well ventilated.

The switch-gear in each panel consists of oil break switch and enclosed fuses, the latter contained in a cast-iron gastight case. Access

can only be obtained to the fuses of each individual panel when the switch is in the "off" position. Fuses are used at the substations in place of "automatics" as continuous attendance is not provided at these points; each motor being protected by an "automatic," a feeder fuse only blows when something is seriously at fault.

Three-phase power transformers, 500-volt secondary pressure, of 670 k.v.a., are erected in these substations to supply the smaller motors, together with 170 k.w. of single-phase lighting transformers, 110-volt secondary pressure.

Distribution.

Mine Cables.—Each shaft has duplicate 3-core cables, 0·08 sq. in. section, insulated with impregnated paper covered with copper tape 15 mils. thick, the whole lead sheathed and armoured with 50 of No. 12 S.W.G. galvanised steel wires separated from the lead.

These cables are carried in the shafts by wrought-iron cleats attached to the beyots placed from 7 yds. to 10 yds. apart, the cleats being bushed with hard wood bushes; the cables are jointed in cast-iron joint-boxes, both the armouring and the copper tape being kept electrically continuous at the joints.

The 3,000-volt armoured cables are carried down four of the pits and extend a distance of 700 yds. from the pit bottom. The cables are hung along the roadways, supported by leather thongs, so that in case of a fall the support will give way without putting serious strain on the cable.

The pit lighting is independent of the power cables; the original wiring (used when the pits were supplied with D.C.) is now fed with A.C. current from the substations above ground.

Mine cables have been provided for the following pits:—

	Depth of Shaft.
Aberaman	300 yds.
Lower Duffryn	348 „
Abercwmboi	300 „
Fforchaman	200 „

Motors of 1,000 B.H.P. were in use below ground in December last.

Overhead Distribution.—The distribution from the substations to the various motors, both 3,000 and 500 volt, consists of bare wires supported on insulators attached to wooden poles or to the existing buildings. These wires are guarded in a similar manner to the transmission wires, and are protected by lightning arresters at the substations.

Where high-tension wires are supported on the existing buildings the conductors are kept 9 in. apart for supports 6 yds. apart, the conductors in all cases being kept well above the ground level.

The connections between the switch-gear and the individual motors consist below ground of 3-core armoured cable, special care being taken to see that the frame of the motor, controller and sheathing of the connecting cable are all in electrical contact with one another and with earth.

Above ground the same method is used for the high-pressure connections, the low-pressure connections being made by single rubber covered wires mounted on insulators, protected by expanded metal guards where accessible.

Earth Connections.—In order to provide a good earth connection in each pit, in addition to the armouring, which has been carefully bonded, a bare copper conductor of 0·1 sq. in. section has been taken down each shaft, from which earth wires, having 25 per cent. greater area than the individual wires in the distributor, have been laid to each motor so as to insure a good earth connection for the motor frames, switch-gear and controller cases.

The neutral point of the star winding of the generators is earthed at the power station, and the neutral point of the 500-volt transformers is earthed at each substation.

Motors.

Three-phase motors aggregating 4,600 B.H.P. were specified for in the first instance, and since the work has been in hand further motors have been added, bringing up the total to date to 6,000 H.P.

The motors may be divided into two classes :—

(1) Variable speed, for haulage and winding.
(2) Constant speed, for driving pans, pumps, screens, conveyors, workshops, and brickyard.

Forty motors of the first type were at work in January, 1906, varying in power from 300 to 25 B.H.P., totalling 3,260 B.H.P., and 37 of the second type, from 180 to 5 B.H.P., totalling 1,450 B.H.P.

Table III. gives a classification of the total power used at these pits in January last, 4,710 B.H.P. being electric, the balance of 7,460 being steam driven, of which a further 1,000 H.P. is being converted to electric driving. Total, 12,170 B.H.P.

TABLE III.

	No. of Motors.	Electric.	Steam.	Total.
Winding	3	280	4,400	4,680
Haulage (above ground) ...	28	2,400	300	4,030
„ (below ground) ...	5	580	750	
Fans	3	380	500	880
Pumps	6	340	450	790
Screens	4	240	—	240
Washery	—	—	430	430
Air compressors	—	—	470	470
Auxiliary motors, conveyors, workshops, brickyards ...	46	490	160	650
Totals	5	4,710	7,460	12,170

In addition 170 k.w. of transformers are used for lighting above and below ground.

Twenty-six of the motors given in Table III., of 3,500 B.H.P., are wound for 3,000 volts, all motors below 50 B.H.P. being wound for 500 volts.

Gearing.—The general method of drive is by cut-steel gear, and in order to reduce the ratio of reduction as far as possible a motor speed (at full load) of 121 r.p.m. was chosen for the 300-H.P. and 290 for the 150-B.H.P. haulage motors.

The motors have been fitted in all cases to existing haulage gears, replacing a steam-engine, arrangements being made so that the haulage could be worked with steam up to the end of the week, the electric driving commencing the following Monday by dismantling the engine and putting the motor and gear in its place.

The high-tension motors are of the protected type, those over 75 B.H.P. having bearings separate from the frame; the slip rings are carried at the end of the shaft and are enclosed when the motors are used underground.

TABLE IV.

	Haulage Motors. Variable Speed.			Motors for Continuous Service. Constant Speed.		
Rated B.H.P.	150	75	50	100	50	25
Volts	3000	3000	3000	3000	3000	500
Diameter of rotor	42·5″	30″	25″	42″	24″	19·25″
Speed (at full load) ...	290	365	365	290	485	485
Efficiency: Full	89·5%	89%	85%	90%	91%	87·5%
¾	89%	88%	84%	91%	90%	88%
½	87·5%	86%	82%	91%	88·5%	87%
Cos ϕ: Full	·78	·82	·72	87	83	·85
¾	·71	·78	·63	·86	·77	·80
½	·60	·68	·5	·82	·65	·70
Maximum starting torque	2·55	2·7	3·3	1·8	3·6	2·5
Air-gap (inches)	·08	·06	·06	·05	·04	·04
Temperature rise	35°C.	39·5°C.	45°C.	37°C.	60°C. *	30°C.
Weight of motor in lbs. without bed plate ...	6,900	3,600	2,900	6,000	3,800	2,150

* 70 B.H.P. motor rated at 50 B.H.P. totally enclosed.

Table IV. gives particulars from the tests of both types of motors.

The switch-gear provided for the variable speed motor control is in each case as shown on Fig. 6. The control panels are erected in brick chambers with an expanded metal front, each high-tension panel having an "isolating" switch (in the case of the motors underground, operating under oil) to allow the whole of the switch-gear, etc., for each individual motor being entirely disconnected from the system; 3-phase oil switch combined with "overload" relay, and series transformer for measuring current.

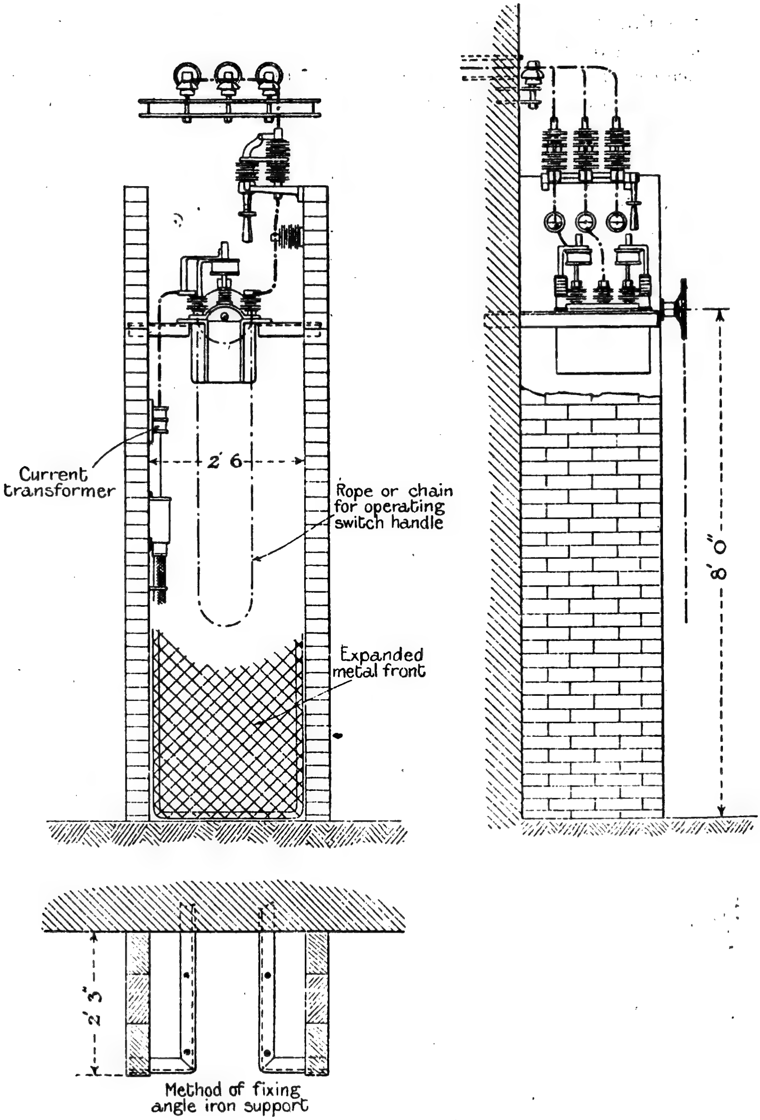


FIG. 6.

Each haulage has an ammeter to act as a guide to the driver, the dial being marked to show the rated working current of the motor and the overload point at which the circuit-breaker will operate, the motor not breaking out of step unless an overload of 2½ times its working current is exceeded.

The controller and high-pressure reversing switch are combined (Fig. 7), and are operated by one handle through gear and levers. The rotors of the haulage motors are wound for 2-phase, the 150-B.H.P. haulage motors having a voltage at starting 390 by $\sqrt{2}$ current, at full load 145 $\sqrt{2}$.

The controller consists of a metal case in which is mounted a revolving drum on which two lines of rubbing contacts are fixed, arranged in

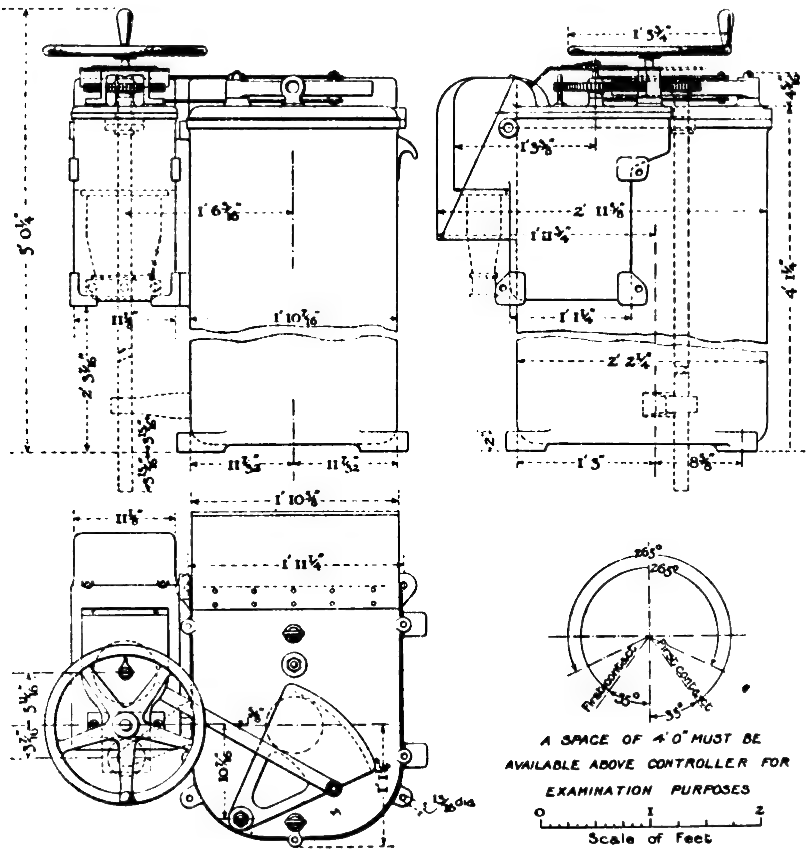


Fig. 7.

parallel spirals; 15 fixed contacts connected to the rotor resistance are placed vertically at each side of the drum (the whole of the contacts operate under oil when used underground). Each of these contacts carries three copper fingers, reinforced by an adjustable flat steel spring. The tips are copper wedges screwed to the end of the fingers, all contacts, both stationary and revolving, being designed to be easily renewable.

The first four sets of contacts are arranged to cut out whole sections of resistance, the remaining contacts cutting out half sections, the reverse action taking place when the resistance is being put in.

The high-tension reversing switch is bolted to the side of the controller. Four contacts controlling two of the three phases supplying the stator are reversed under oil by a revolving switch.

In order to provide for smooth operation the controller provides for 26 motor speeds. Fig. 8 gives the torque diagram, showing range of the controller.

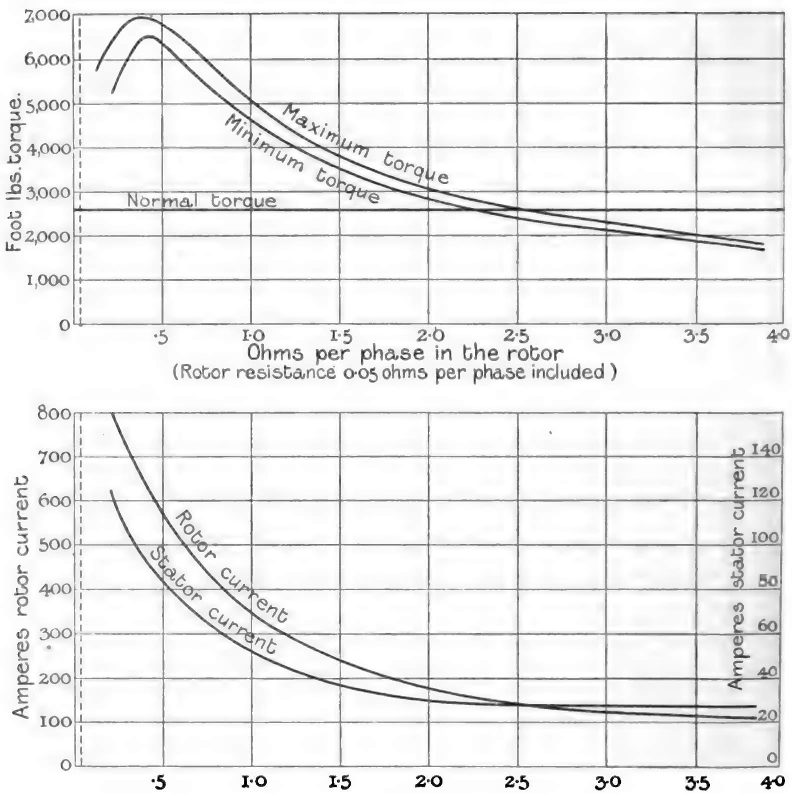


FIG. 8.

The resistances for the rotor circuit are cast metal grids. These are mounted in frames placed close to the controller, the frames being well ventilated and protected by expanded metal guards; the connections between the resistances and the controller are carried in an earthed iron pipe or protected by expanded metal guards.

Fig. 9 gives the characteristic curves of the 150-B.H.P. haulage motor, showing when working from three-quarter load to 25 per cent. overload an average efficiency and power factor of 89 and 78 per cent. respectively, the slip at full load being 3 per cent.

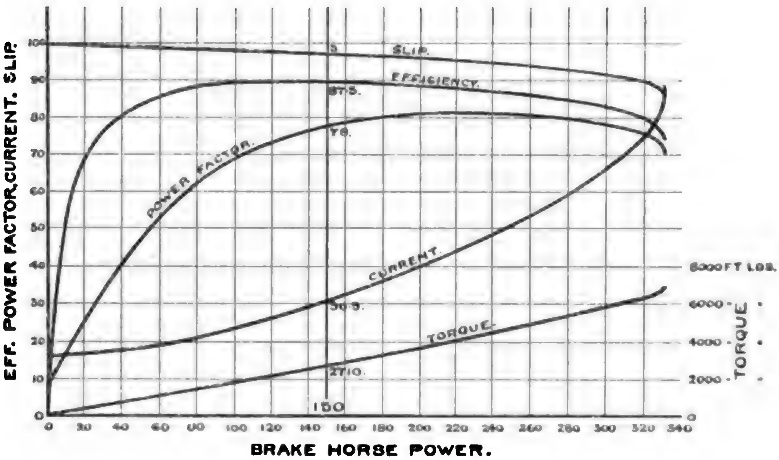

EFF. POWER FACTOR, CURRENT. SLIP.
SLIP.
EFFICIENCY.
POWER FACTOR.
CURRENT.
TORQUE.
87·5.
78.
30·5.
2710.
150
8000 FT LBS.
6000
4000
2000
TORQUE
BRAKE HORSE POWER.

FIG. 9.

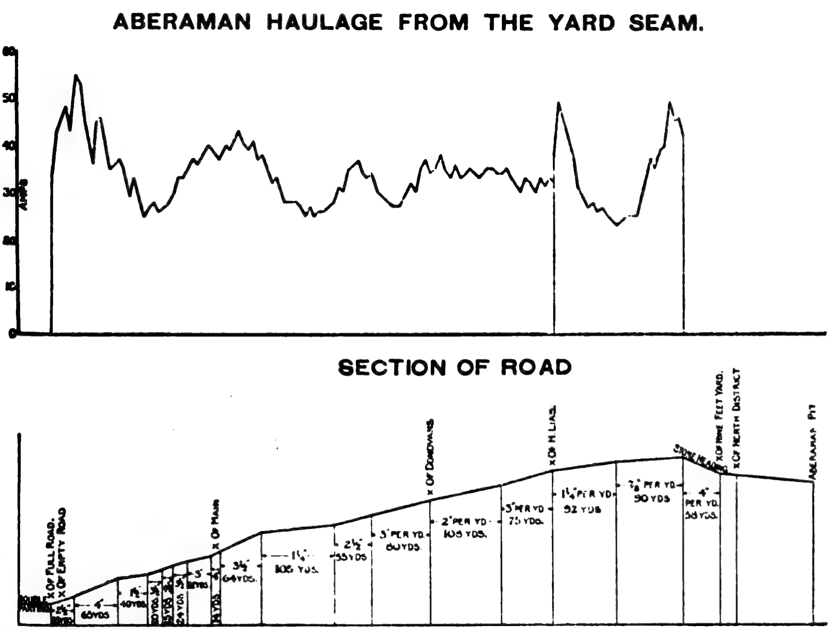

ABERAMAN HAULAGE FROM THE YARD SEAM.
AMPS
SECTION OF ROAD
X OF FULL ROAD.
X OF EMPTY ROAD
X OF MAIN
X OF DONOVANS
X OF H. LIAS.
X OF NINE FEET YARD.
X OF NORTH DISTRICT
ABERAMAN PIT
STONE HEADING
65 YDS
40 YDS
64 YDS.
105 YDS.
55 YDS
60 YDS.
105 YDS.
75 YDS.
92 YDS
90 YDS
58 YDS.

FIG. 10.

Application of Electric Driving.

The following are representative instances of drives for haulage, fans, pumps, winding, etc.

Main and Tail Haulage.—Fourteen of these are driven by 150-B.H.P., 3,000-volt, 290-r.p.m. variable speed motors. The leading details of the gearing and weight handled by one of these haulages, arranged with two drums in tandem, are given in Table V.

TABLE V.

Diameter of drums	4 ft. 6 in.
Drum, cast iron helical gear ...	84 teeth, $2\frac{1}{2}$ in. pitch × $9\frac{1}{2}$ in. wide.
Drum pinion	28 teeth, $2\frac{1}{2}$ in. pitch × $9\frac{1}{2}$ in. wide.
Motor cut steel spur wheel ...	66 teeth, $2\frac{3}{8}$ in. pitch × $9\frac{7}{8}$ in. wide.
Motor pinion	22 teeth.
Length of rope	1,450 yds.
Weight of rope	2·12 tons.
Diameter	$\frac{3}{4}$ in.
Number of trams	20.
Weight of trams	20 × 9 cwt. = 9 tons.
Number of shackles	19.
Weight of shackles	19 × 30 lbs. = ·25 ton.
Weight of coal per journey ...	20 × 26 cwt. = 26 tons
Total weight hauled	37·3 tons.
Time occupied per journey ...	$4\frac{1}{2}$ mins.
Speed of journey	$5\frac{1}{2}$ miles per hour.

The gradient is shown on Fig. 10, and the readings corresponding to the different points on the journey were obtained by signalling as the tram passed. It will be noticed that when five-sixths of the journey is complete the trams are stopped and the tail rope put on, the journey being completed with trams under brake control.

The energy required averages one unit per ton of coal hauled, Table VI. giving representative instances.

TABLE VI.

Length of road in yards ...	1,100 ...	1,320
Gradient, inches per yard ...	1 to $4\frac{1}{2}$ ...	1 to 4
Time per journey, minutes ...	$7\frac{1}{2}$ ...	9
Coal per journey, in tons ...	27 ...	27
Completed journeys per day ...	17 ...	19
Coal hauled per day	460 ...	520
Units per day	425 ...	490
Units per ton of coal hauled ...	·92 ...	·94
Maximum k.w. input into motor...	286 ...	242
Load factor of haulage (250 working days)	4·25 % ...	5·8 %

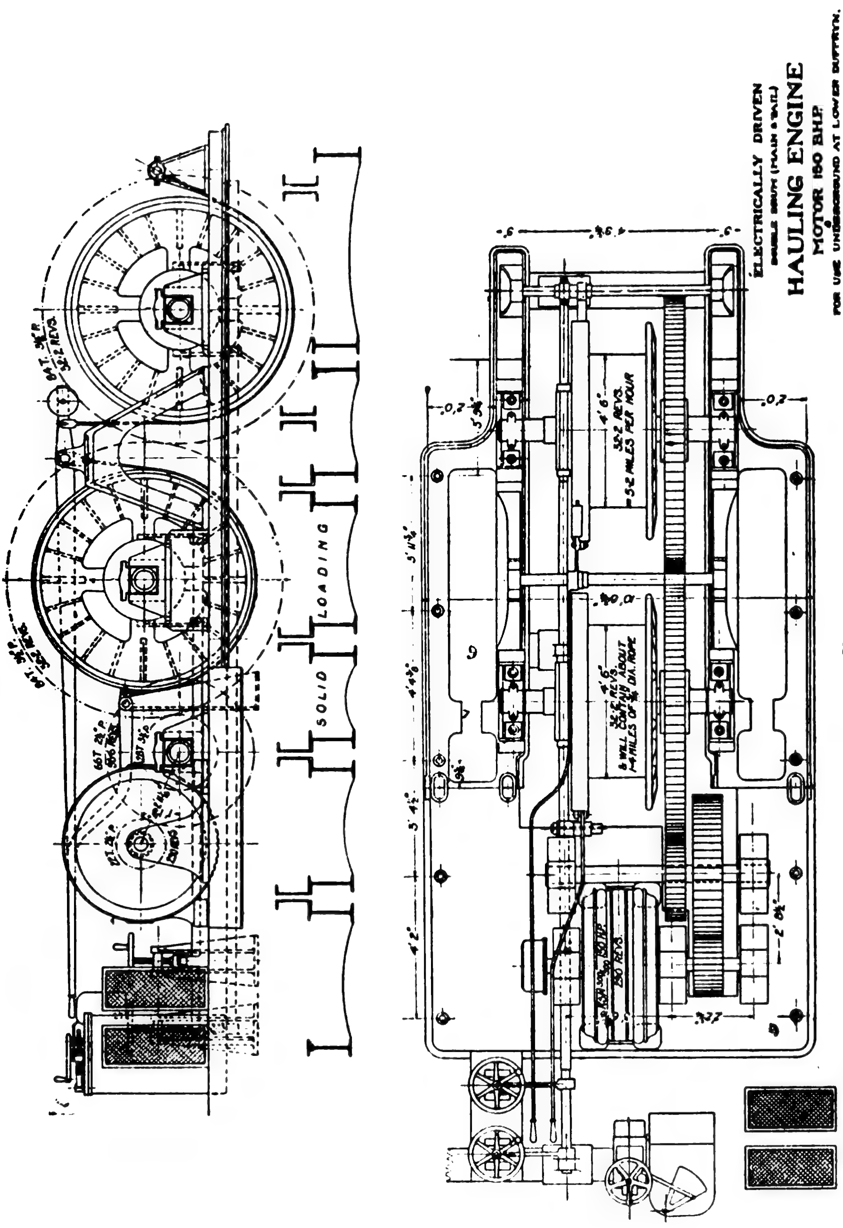

ELECTRICALLY DRIVEN
DOUBLE DRUM (MAIN & TAIL)
HAULING ENGINE
MOTOR 150 B.H.P.
FOR USE UNDERGROUND AT LOWER DUFFRYN.
SOLID LOADING
4'6"
32.2 REVS.
5.2 MILES PER HOUR
150 H.P.
150 REVS.

FIG. 11.

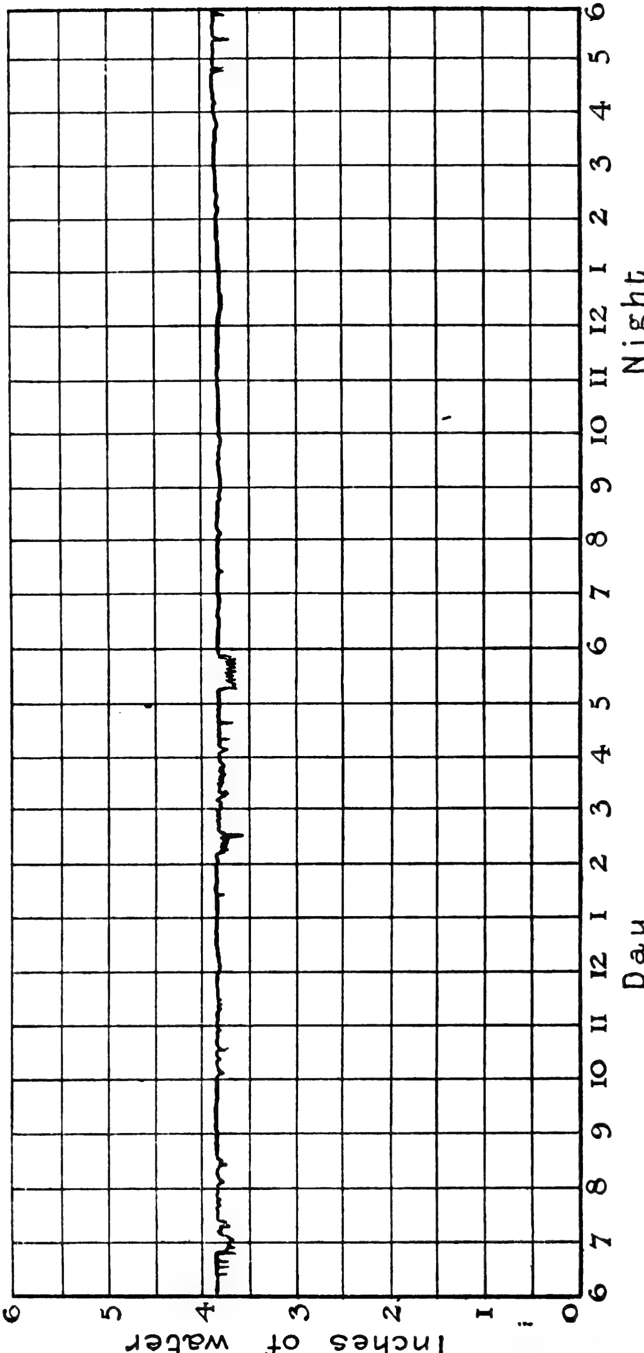

Inches of water
0
1
2
3
4
5
6
Day
Night
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
9
10
11
12
1
2
3
4
5
6

Fig. 12.

These low load factors are due not only to the intermittent working of the journeys, but to the power required at starting and on mounting a gradient.

Before conversion, when the haulages were steam driven, the engines slowed down at each heavy gradient, but now the haulage is electric 3-phase, the speed is maintained whatever the gradient, and, in consequence, the power taken momentarily is great. The large power taken by "main and tail" haulage shows the great advantage of the continuous haulage system where roadways will allow this method of operation.

Fig. 11 shows the general arrangement of one of the underground haulages which has been converted from steam. Drum speed 32 r.p.m., equivalent to 5 miles per hour.

Gearing.—Drum cast iron double helical: Teeth 84, pitch 3½ in., width 9½ in. Drum pinion: Teeth 28. Motor spur wheel, cut steel: Teeth 66, pitch 2⅝ in., width 8⅝ in. Motor pinion, cut steel:

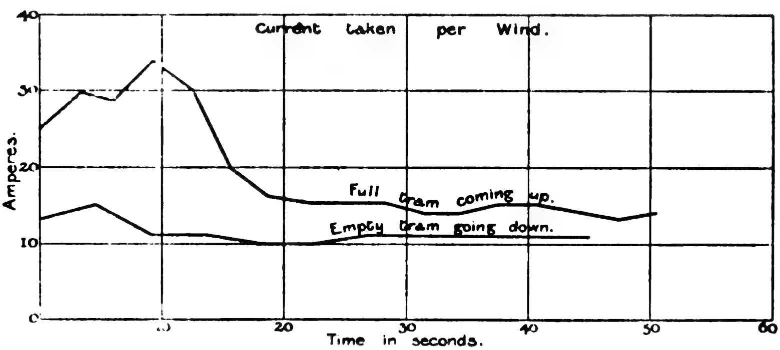


FIG. 13.

Teeth 22. The operator faces the motor, having the clutches on his left, brake levers and ammeter in front of him, and the controller on his right.

Fans.—180-B.H.P., 3,000-volt motor, protected type, running at 290 r.p.m., fan being rope-driven at 175 r.p.m. Air delivered by fan, 150,000 cub. ft. per minute with 3⅝ in. water gauge.

Fig. 12 shows air pressure chart for 24 hours. This chart gives a direct indication of regularity of speed of the power station. The air pressure secured by this method of drive is more uniform than is usually obtained with steam-driven fans.

The switch-gear used is of the same type as that employed for the haulage motors, with the exception that the starter is a liquid resistance.

The fan motors are run at full load continuously, being shut down for examination and cleaning for 10 minutes every three weeks.

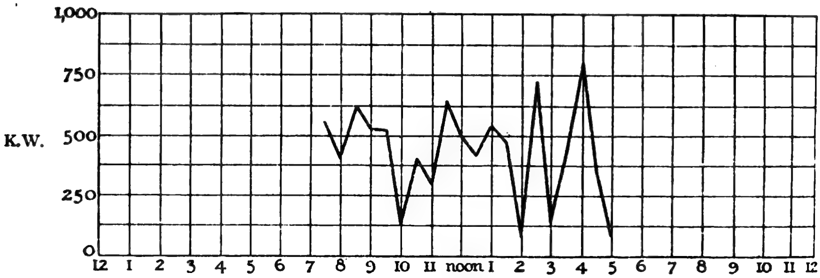
Screens.—60-B.H.P., 3,000-volt enclosed motor, 485 r.p.m., the screens being rope driven. Switch-gear as above. Liquid starter employed,

Aerial Rope Ways.—15-B.H.P., 500-volt motor, 575 r.p.m., belt driven. Liquid starter.

Pumps.—100-B.H.P., 3,000-volt motor, 485 r.p.m. Three-throw Uskside ram pump, rope driven, 9 in. cylinders, 15 in. stroke, 22 r.p.m., delivering 13,000 gallons per hour against a head of 1,020 ft.

40-B.H.P., 500-volt enclosed motor, 720 r.p.m., driving centrifugal pump direct against head of 100 ft.

Winding.—100-H.P., 3,000-volt motor, r.p.m. (full load) 290. Depth of pit, 90 yds. Time occupied in wind, 40 seconds. The cage holds



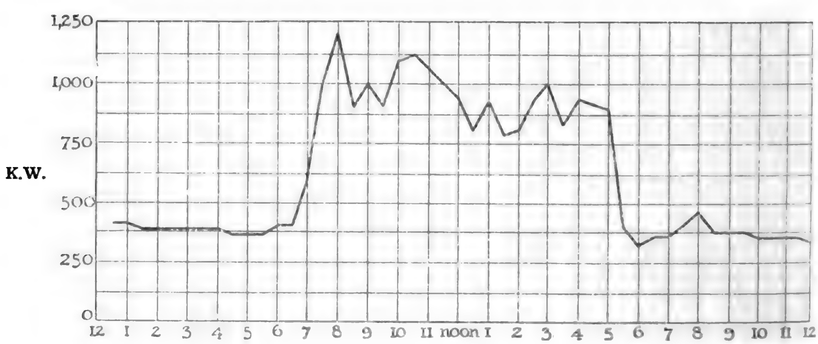


FIG. 14.—Load Curves.

one tram. Output, 70 tons of coal per hour. As the workings are being opened out only 200–300 tons per day are being dealt with, out of the daily capacity of 600–700 tons.

A similar winder is used for men only. Depth of pit, 270 yds.

An underground winder is in use at Fforchaman in a staple pit. Depth, 100 yds. The winder is driven by 80-H.P. motor, 360 r.p.m. (full load), 3,000 volts, working a single cage holding one tram, the load being balanced by a weight.

Fig. 13 shows the current taken per wind. The time occupied is 50 seconds. The maximum speed of the rope is 486 ft. per minute. Output at the rate of 30 tons per hour.

Load Factor—Power Station and Individual Motors.

Load Factor on Power Station.—Fig. 14 shows that with motors of 1,366 B.H.P. connected, a daily output of 4,400 units, and maximum demand of 800 k.w., the load factor is 22·5 per cent.

With motors of 3,900 B.H.P. connected, a daily output of 14,900 units, and maximum load of 1,200 k.w., the load factor is 51 per cent.

The annual load factor is lower than the above figures, as the power station only supplies for ventilating, pumping, and a small amount of lighting on 1½ days of each week; in addition, stop days and holidays have to be allowed for.

Tests on individual "main and tail" haulages working 17–20 journeys per day give load factors (based on 250 working days) of 4½–6½ per cent.

Ventilating fans give a load factor of nearly 100 per cent.

With pumping, the load factor depends on position and quantity of water, the best load factor being obtained when storage allows the pumping to be confined to the night shift, the pumps only being run when the haulages are not in use. By this means no extra capacity in generating plant is required for driving the pumps.

Screens and conveyors have a load factor of 30 per cent.

Workshops and auxiliary motors taken collectively have a load factor of 33 per cent. (load factor for individual motors being one quarter of this figure).

The maximum sustained load on the power station reached during the last quarter has been 1,400 k.w.; the output being at the rate of 4,500,000 units per annum, this gives a load factor of 37 per cent., and if a year is taken without addition of further motors, the load factor with the present methods of working would lie between 35 and 40 per cent.

This high load factor is obtained by supply to seven pits, and results from the combined supply of a number of drives, many of which have exceedingly low load factors.

These figures indicate the difficulty a small colliery has in converting from steam to electric driving, as the capital charges due to the low load factor, extra cost of reserve plant, and greater cost per k.w. for small units, will result, even with cheap fuel, in much higher costs than those given in this paper; and it is works of this description that offer the best opportunity to power companies, as it is only in cases where a considerable proportion of the power is required for pumping that an isolated pit requiring main and tail haulage could obtain a sufficiently high load factor to give low working costs when generating with its own plant.

Costs.

Power Station.—Buildings, steam plant, generators, and switch board per k.w. of plant erected (normal rating)	£11 10s. per k.w.
The cost of the equipment per B.H.P. outside station, transmission and	

distribution (overhead and underground) substations, transformers, and switch-gear	£2 12s.
Motors, controllers, switch-gear, and gearing, per B.H.P.	£3 18s.—£6 10s. per B.H.P.

The cost per unit delivered to the colliery transmission lines, with an output of 4½ million units per annum, load factor of 37 per cent., using unwashed small coal (calorific value 13,000 B.Th.U.) costing 4s. 2d. per ton :—

Works costs	0·18d.
Interest and depreciation 10 per cent. on power station	0·185d.
Total	0·365d.

The reserve plant in the power station at present is 100 per cent.; this will fall to 66 per cent. when the power station is completed by the addition of a further 1,500-k.w. unit, and the cost will be reduced to under 0·3d. per unit delivered to the colliery mains at a load factor of 45 per cent.

The whole of this contract has been carried out by the Electrical Company under the supervision of Mr. A. E. Hadley, with Mr. F. J. Rynd as Resident Engineer. My best thanks are due to these gentlemen for the assistance given me in preparing this paper, and also to Mr. E. M. Hann, the Engineer and General Manager of the Powell Duffryn Company, in conjunction with whom I have carried out this work.

MANCHESTER LOCAL SECTION.

ELECTRIC WINDING IN MAIN SHAFTS CONSIDERED PRACTICALLY AND COMMERCIALLY.

By W. C. MOUNTAIN, Member.

(Abstract of Paper read in Manchester, Jan. 16, 1906, *and rediscussed in London, Mar.* 22, 1906.)

The subject of main shaft winding in collieries is one of considerable interest, not only to the mining engineer, but also to those associated with the application of electricity to mines. There is no doubt that in the past the class of winding engines used in our collieries in the United Kingdom and also abroad has been very far from economical. But colliery owners are now recognising the importance of reducing the consumption of coal in their collieries.

The writer has found that the consumption of coal used for the winding engines, pumping, hauling, screen driving, and the other requirements has been as high as 13 per cent. of the total output of coal produced by the colliery, whereas in modern collieries the consumption has fallen to about 2 per cent.

It is always customary in considering the consumption of coal at a colliery to express it as a percentage of the total output, and therefore the writer proposes, in dealing with the costs of main shaft winding, to consider what percentage of the output would be required with the various classes of winding machinery.

It is a well-known fact that in a large number of collieries—in fact, most of them—there is a very considerable amount of coal produced, either in the form of slack, dust, or smudge, which is practically unsaleable; this coal is generally used under the boilers, and as it is practically valueless, any saving which can be effected in the cost of working, by reducing the consumption of coal, has to be considered with regard to the market value of such coal.

Of course, there are other savings, such as the reduced number of boilers, also stokers and ashmen, which all have to be taken into account; but, after all, when considering any change in the system of winding in an existing colliery, or the application of winding to a new colliery, the question is the cost at which 100 tons of coal can be wound by the different systems.

The object of this paper is to deal with the subject in as practical a manner as possible, but principally from a commercial standpoint,

and, therefore, the writer does not propose to give any very extended descriptions of electric winding plants, because these have already been so fully described by others who have contributed papers on the subject. Briefly, however, the systems of winding may be reduced to the following :—

1st. Double cylinder horizontal winding engines.
2nd. Compound horizontal winding engines.
3rd. Either type of engine worked condensing, by which a distinct gain in economy would be obtained.
4th. Electric winding by means of 3-phase motors, either driving direct, or directly geared to the winding drums and taking their supply of current direct from the power mains.
5th. By continuous-current motors operated in the same manner.
6th. By continuous-current motors driving direct, or directly geared to the winding drums, the supply of current from the power mains being regulated by a balancer with heavy flywheel. This supply may be either continuous or 3-phase.

The supply of current to the electric systems of winding may, of course, be obtained either from a power station at the colliery—assuming the winding is at one colliery only—or from a central power station, belonging to the colliery company, supplying current to a group of collieries; or it may be obtained from a power station of an electric supply company (of which a considerable number are being erected at the present time throughout the United Kingdom).

In dealing with the question of electric winding from a practical standpoint, the great difficulty which at once presents itself is the enormous amount of current and consequent power required for acceleration, compared with the average quantity of current or energy required throughout the wind, and this becomes a matter of very serious consideration when it is necessary to accelerate very quickly in order to get the output from the colliery.

When approaching the question of electric *versus* steam winding, it is not desirable to start off at once with the assumption that steam winding is necessarily very wasteful and to take as a standpoint a very uneconomical steam winding engine. This has unfortunately been done in the past by some who have written papers on this subject, and, as the data given in such papers are very unreliable, the writer has endeavoured, through the kindness of many friends connected with collieries, to obtain actual data, giving the consumption of coal per 100 tons wound, and the wages of the winding engine man, stokers, and ashmen.

These are given in Table I.

From this table it will be noted that the cost of winding varies considerably. No. 7 comes out the cheapest, and this is due, of course, to the large output, viz., 3,186 tons, wound in 11 hours, and the coal burnt in this case is valued at only 3s. per ton.

Comparing this with No. 2, where the output is 3,360 tons in 14 hours, and the value of the coal used for winding 1s. 6d. per ton only, the cost works out at 5s. 2d. per 100 tons, but this is due to the more expensive winding engine.

In No. 4 Colliery the cost works out at 16s. 11d. per 100 tons wound, but it must be observed that this is with an engine 30 years old, and which has been in continuous operation. To arrive at this figure the original value of the engine when new is put in. Of course, with the depreciated value the cost per 100 tons would be considerably less.

No. 9 Colliery is also interesting, as the high cost in this instance is entirely due to the engines being too large for the work. It will be noted that the time of winding is 34 seconds, and the time for banking 84 seconds. If there were sufficient coal to enable the engine to do its full duty, *i.e.*, to wind certainly two and a half times as much coal as at present, the cost per 100 tons would be 12s. At the same colliery it will be noted that when winding from another shaft, although the time for winding is 61 seconds, the cost is 11s. 5½d. with an almost similar engine, but there again the engines are undoubtedly far too large for the work, and thus account for the increased cost due to the heavy charge for interest and depreciation.

The conclusion to be drawn from this table is that, with reasonably economical engines, coal can be wound, including interest and depreciation, at about 6s. to 7s. per 100 tons, and where the coal used is of very little value this cost can be still further reduced ; then, again, if the pits can be run double shift, so that the heavy charge for interest and depreciation could be spread over an increased output, the cost would become lower still.

With the exception of one or two cases, many of these engines, although large, are of a somewhat old-fashioned type, but it will be seen at a glance what exceedingly good results are obtained by modern engines, as in Nos. 1, 2, and 7, and it is upon the results obtained from such engines that electrical engineers have to base their calculations in dealing with this subject.

The writer now proposes to consider what results can be obtained from really high-class steam winding engines, and for this purpose he has been in communication with the principal makers, who are prepared to guarantee the results which are shown in Tables II., III., and IV.

The data given in Table II. were kindly supplied to the writer by Messrs. Fraser and Chalmers, who have had a very large experience in the building of winding engines, both for abroad and for this country, and it will be noted that the costs per 100 tons wound vary from 6s. 3d. on a pit 500 yards deep, winding 1,000 tons per day, to 6s. 6½d. when winding 2,000 tons per day from a pit 700 yards deep. These particulars are based on a winding period of 10 hours per day.

The next example of winding with high-class steam winding engines is prepared from data kindly given by Messrs. Markham and Co., of Chesterfield, who have also had very considerable

experience, and build very high-class engines. It is interesting to note how very nearly these figures correspond with the costs of winding with Fraser and Chalmers engines.

The results in Table IV., it will be noted, are based on the assumption that the output is wound in $7\frac{1}{2}$ hours per day, which necessarily means a somewhat larger winding engine for the same duty, and, as the engine is more expensive, the amount to be paid for interest and depreciation is also somewhat excessive, but it shows how extremely economical this type of engine would be if the winding were increased to two shifts per day. (See Tables II., III., and IV.)

Condensing.—In giving the above figures of the cost of steam winding, it will be noted that these results are obtained with the engines working with high pressure, but there is no doubt that a very considerable economy, certainly from 10 to 15 per cent. in the coal consumption, can be obtained by condensing, and in comparing the figures for steam winding with the figures for electric winding—in which the consumption of steam per kilowatt is taken at 25 lbs., including the condensation in steam pipes and the steam required for feed pumps—it must be borne in mind that this result is obtained by condensing; therefore, the results of electric winding are shown rather more favourably than they would be if the engines were working non-condensing, as in steam winding.

These tables have been extended to show the cost and also the consumption of coal per 100 tons wound. Interest and depreciation are added at the rate of 10 per cent. for the winding engines, and also for the boilers.

Table V. shows the probable cost of an electric winding plant suitable for capacities of—

No. 1. 1,000 tons per day, 500 yards deep.
No. 2. 1,500 tons per day, 500 yards deep.
No. 3. 2,000 tons per day, 700 yards deep.

And these may be taken as typical winding conditions in large collieries. The table gives—

(*a*) The total cost of the plant.
(*b*) The consumption of current.
(*c*) The percentage of coal used compared with the output.
(*d*) Estimated cost of winding, including coal, engineman's wages, etc., etc.
(*e*) The amount which must be added to cover the interest and depreciation on the first cost of the plant.

It will be seen that these figures do not compare at all favourably with the results which have been obtained from high-class steam winding engines, and this is largely due to the heavy first cost of the plant.

It may be argued—and with a great deal of justice—that the generating plant can be utilised for other purposes during the time that it is not used for winding, and there is no doubt that the item for interest and depreciation would be greatly reduced if this plant were

Name of Colliery.	Distinguishing No.	Cylinders.	Steam Press.	Revs. per Wind.	Drum.			
		Dia. and Stroke.			Type.	Dia.	Width.	:
Bolsover Colliery Co. ...	1	{32 × 72 / 2 Cyls.}	—	21½	Conical	16 to 17ft.	—	
Denaby and Cadeby ...	2	45 × 84	80	24¾	Conical	17 to 33ft.	16ft. 0in.	1
Tredegar Coal Co.... ...	3	{18 × 28 / 48}	140	23½	Parallel	11ft. 0in.	8ft. 6in.	
A Lancashire Colliery ...	4	{36½ × 78 / 2 Cyls.}	60	80 *a*	Parallel	18ft. 3in.	3ft. 2in.	:
Richard Evans	5	36 × 78	80	—	—	—	—	
Silkstone Colliery	6	{32 × 72 / 2 Cyls.}	120	50 *a*	Parallel	17ft. 0in.	7ft. 8in.	1
H. Rhodes, Rotherham...	7	40 × 78	105	24	Parallel	22ft. 0in.	12ft. 0in.	5
Hulton Colliery	8	32 × 72	80	—	Parallel	15ft. 0in.	8ft. 0in.	4
" "	9	36 × 72	80	—	Parallel	18ft. 0in.	8ft. 9in.	4
Atherton Collieries... ...	10	{22 × 54 / 2 Cyls.}	100	35½	Parallel	{10ft. 0in. / 13ft. 1in.}	5ft. 0in. / 5ft. 0in.	4 / 3
Hickleton Main	11	40 × 78	100	25	Parallel	21ft. 6in.	12ft. 0in.	5
Sherwood (No. 2 winder)	12	{26 × 54 / 2 Cyls.}	127	38·3	Parallel	11ft. 0in.	10ft. 0in.	5

H.

Wound.

d.
4
0
3

d

H.

Wound.	Interest and Depreciation on Boilers at 10 per Cent. per Annum.	Interest and Depreciation on Boilers per Day.		Interest and Depreciation on Boilers per 100 Tons Wound.	Total Cost per 100 Tons Wound, without Interest and Depreciation.		Total Cost per 100 Tons Wound, including Interest and Depreciation.	
d.	£	s.	d.		s.	d.	s.	d.
4	75	6	0	7·2d.	3	4	6	3
0	112	8	11½	7·2d.	2	8½	5	1½
3	225	18	0	11d.	3	4½	6	6½

FIELD.

per Day.	Interest and Depreciation on Boilers per 100 Tons Wound.		Total Cost per 100 Tons Wound, without Interest and Depreciation.		Total Cost per 100 Tons Wound, including Interest and Depreciation.	
d.	s.	d.	s.	d.	s.	d.
5	1	3	3	5½	6	8½
10	0	10½	2	9	6	0
0	1	2½	3	2	6	8½

used during the night for coal cutting, pumping, etc. Unfortunately, the power required in collieries for night work bears a small proportion to that required for day work, as it is during the day that all the haulage is required in order to bring the coals to the pit bottom for the winding engines.

The possibility of competing successfully with steam can be considered from a commercial standpoint when the supply for the electric winder is taken from a power company, and a further table is given based upon the three examples, in which the cost of the generating plant is eliminated, and, assuming the value of the coal for producing steam at 3s. 6d. per ton (as taken in Table V., dealing with the cost of electric winding), it will be seen that the cost of labour, interest and depreciation alone exceeds the cost at which coal can be wound with high-class steam winding engines; this result being due to the heavy first cost of the electrical winding gear and balancer.

Compared with the worst examples of steam winding, where the cost works out at 16s. 11d. per 100 tons wound, the amount which the consumer can afford to pay an electric supply company for current would be :—

On 1,000 tons, 500 yards deep ... ... 0·35 pence per unit.
On 1,500 tons, 500 yards deep ... ... 0·275 pence per unit.
On 2,000 tons, 700 yards deep ... ... 0·18 pence per unit.

But the question would at once arise whether it is not desirable to install high-class steam winding engines and wind the coal at a much lower cost than can be done electrically.

It may be argued that the figures given above are estimated figures, but, by the courtesy of the Electrical Company, the writer is able to deal with results which have been published—as regards electric winding—and which were obtained at the Grand Hornu New Mine, in Belgium. This colliery is favourably situated (as regards the application of electricity to winding) as there are three pits, all of moderate capacity, placed at some little distance apart, so that there was undoubtedly a good reason for centralising the generating machinery and working the pits electrically.

From the data supplied the following table of results has been compiled :—

TABLE VI.

Grand Hornu Mines.

Output, Tons of Coal per day of 24 hours	1,560
Depth of Shaft, yards	766⅔
Hours worked per Day	24
Tons of Coal per Hour	65
Tons of Coal per Wind	2·6
Number of Tubs	6
Weight of each Tub, in cwts.	4·1
Weight of Cages, Chains, etc., in cwts.	39·3

Weight of Rope, in tons	...	11
Value of Coal Burnt per Ton	...	4s. 4d.
Cost of Electricity per k.w.-hour	...	0s. 3d.*
Days Worked per Year	...	250
Total Cost of Winding per 100 Tons	24 hours shift ...	13s. 6d.
	16 " " ...	15s. 6d.
	8 " " ...	17s. 6d.
Cost of Winding per 100 Tons, without interest and depreciation	...	11s. 4d.

* Taking coal consumption at $2\frac{1}{2}$ lbs. per I.H.P.-hour, and correcting for English wages.

The cost of 13s. 6d. per 100 tons is only obtained by the plant running twenty-four hours per day. If run for eight hours per day, the cost per 100 tons is much higher (17s. 6d.) and the comparison more unfavourable.

This shows that, with this up-to-date system of electric winding and with 5 per cent. interest and 5 per cent. depreciation added, the cost of winding is, roughly, twice what the cost is shown to be with by no means up-to-date steam winding engines in this country.

TABLE VII.

Estimated Net Cost of Electric Winding, exclusive of Electric Energy.

	Interest and Depreciation per 100 Tons Wound.	Wages of Men per Shift.		Wages of Men per 100 Tons Wound.		Total Wages per 100 Tons Wound.	Oil and Stores per 100 Tons.	Total Cost of Winding per 100 Tons including Interest and Depreciation.
		Winders.	Switchboard Attendants.	Winders.	Switchboard Attendants.			
I.	6/10	6/-	4/2	$7\frac{1}{2}$d.	5d.	$1/0\frac{1}{2}$	3d.	$8/1\frac{1}{2}$
II.	5/8	6/-	4/2	5d.	$3\frac{1}{4}$d.	$8\frac{1}{4}$d.	3d.	$6/7\frac{1}{4}$
III.	5/8	6/-	4/2	$3\frac{1}{2}$d.	$2\frac{1}{2}$d.	6d.	3d.	6/5

Messrs. Siemens Brothers and Company (who have done a considerable amount of electric winding work on the Continent) have been exceedingly kind in supplying information. The figures which they give as to the total cost of their winding plants (exclusive of the generating plants), in three of their largest installations, namely—

Zollern II.,
Stinnes plant, and
De Wendel plant,

go to confirm the estimates which the writer has personally made, and the cost of the electric winding plants given in Table V.

To Messrs. Siemens Brothers is due the credit for the introduction of the Ilgner system, coupled with the Ward-Leonard system of control, and there is no question that for successful winding the adoption of a system of this kind is absolutely necessary if heavy winding is to be done with any possibility of it being a commercial success.

The author regrets that, for heavy winding, he is not able to make out a better case than is shown by the figures in this paper, when the winding is considered on fair and proper lines, *i.e.*, in comparison with engines equal to those used for driving the generating machinery in an electrical installation. It must not, however, be inferred that there is no field for the successful application of electricity to winding in small collieries, or to groups of collieries which are dealing with small outputs and very moderate depths, but it does appear that for really heavy work, such as that referred to in Tables I., II., III. and V., colliery owners would be ill-advised to spend the large additional sum required for electric winding plant when there is so little prospect of getting an adequate return, and when they can spend their money to much greater advantage in electrifying their haulage, pumping, coal cutting, drilling, and the surface driving arrangements.

NEWCASTLE LOCAL SECTION.

ELECTRIC WINDING CONSIDERED PRACTICALLY AND COMMERCIALLY.

By Gerald Hooghwinkel, Member.

(*Abstract of Paper read in Newcastle, Mar.* 12, 1906, *and rediscussed in London, March* 29, 1906.)

It would seem a thankless and difficult task to take up once more the defence of the electrical winding engine against the many one-sided attacks levelled against it. These attacks have hitherto mostly come from practical, well-meaning mining men, who were loth to see their old steam-eating friends disappear, and who looked with concern and misgivings at the apparently high first cost of the electrical substitute. They were backed up by the manufacturers, who gave fantastic low figures for the steam consumption of their makes, which brought these figures down to the vanishing point. All these well-meant attacks were mere assertions of the superiority of the steam winder in their writers' opinion, without seriously discussing the actual merits or demerits of its would-be electrical supplanter. Sound theoretical considerations were hardly ever brought forward, as far as the electrical plant was concerned, and actual figures were difficult to obtain in the early stage of this new application of electricity to colliery plant.

It is different, however, if these assertions emanate from the pen of a well-known and esteemed member of the electrical fraternity, and much harm may be done by his conclusions to the non-electrical mind of the mining engineer or colliery manager.

The task of refuting these conclusions, however, is by no means an easy one. The figures given, although all more or less erring on the safe side where the electrical equipment is concerned, are, on the other hand where he deals with the steam winder, apparently sound enough. The conclusions are, roughly, that electric winding has a future in small collieries for lifting coal from moderate depths, or in combinations of such collieries, but not in collieries where large outputs have to be wound from great depths. The author of the paper in question does not mention whereabout the boundary-line of output and depth must be drawn, but I am inclined to believe that this boundary-line will gradually shift towards the heavy outputs from far greater depths than

are now dreamed of. If we remember the small electric locomotive drawing a train in the Berlin Exhibition not so very many years ago, and we look on the heavy electric high-speed locomotives drawing express trains on the New York Central Railway and on the Swedish State Railways at the present time, we may conceive what can be done. The more so as the conditions of heavy locomotive work are comparable to winding in many respects. Heavy loads, frequent starting and stopping, quick acceleration and retardation, are met with in both cases, although the limited boiler capacity in the steam locomotive is another disadvantage in the case of the latter's struggle against electric driving.

Mr. Mountain starts by securing, in advance, for his figures a reputation of reliability, contrary to those given by the few other writers upon the subject, whose figures are stated to be "very unreliable," and consequently ruled out of court. Of course this is the easiest way of disposing of any opposition, but as I was among the first to deal with the subject under discussion, after first having acquired a good deal of practical experience with electrical winding plant, I may perhaps be forgiven for reviewing these few figures.

For an electrical winding plant designed for a daily output of 2,000 tons from a depth of 600 yards, I have calculated a steam consumption per *useful* H.P. hour in *ordinary* everyday practice of 30 lbs. dry steam of 160 lbs. pressure. The corresponding figure for the Zollern II. Colliery, which was obtained much later by an official test of the German Boiler Insurance Company in the beginning of last year during an ordinary day's (twenty-four hours) running, including the winding of 1,000 men (at reduced speed), rope inspection, and the lowering of materials, came to 29 lbs. of steam by an output of 2,500 tons from 330 yards. This engine, however, is designed for nearly double that output, so the figures would have been considerably better for the full output. During an eight hours' shift, raising 1,300 tons of coal, the steam consumption was only 24 lbs. A still lower figure was obtained at the De Wendel Colliery, where 25 lbs. of steam were required per useful H.P. hour in twenty-four hours (3,000 tons, 770 yards).

For electrical winders of this class and output, 25 lbs. of dry steam of 150 lbs. pressure per *useful H.P. hour on the rope* may therefore be considered a correct figure, proved in actual everyday practice.

The other figure previously given by me was 100 lbs. of steam (at 100 lbs. pressure) as an average figure of *existing* steam winders per useful H.P. hour on the rope in everyday working. This figure was obtained by averaging over fifty collieries, while discarding all those above 200 lbs. Steam winder makers have challenged this figure, giving 40 or even 30 lbs. of steam per horse-power; but even granted that such a figure per *useful* (coal only) H.P. hour on the rope could be obtained during steady winding, the long stops and slower winding of miners and timber would soon bring this figure to a level of at least 50 lbs. with the best modern winding engine running condensing.

The very examples of modern steam winding given by Mr. Mountain and taken from actual practice correspond to steam consumptions of

from 140–50 lbs. steam per useful H.P. hour, while 125 lbs. of steam was required by the winding engine at the Hulton Colliery, the manager of which put his steam consumption at 25 lbs. per horse-power. The average of his thirteen examples is 90 lbs.

The enormous savings in steam consumption and coal may therefore be estimated by these practical results. But wages are also reduced. The engine-man at the winding engine need not be such a highly-paid mechanic as in the case of the steam winding engine, as the winding is much simpler and easier, and nearly all automatic, so that over-winding and too-quick braking need not be feared. As no separate boilers are needed for the winding plant (the electric power station supplying the total plant at the colliery), no separate stokers are required, but only a small proportionate part of the wages at the power house. Less wear and tear, and therefore maintenance, on steam engines (steady load), winding ropes (no jerkings and vibrations due to piston-throw) and frame, complete the other savings.

The fact that the results of Mr. Mountain's comparisons show such a disadvantage to the electrical winder, notwithstanding savings on every item in the running costs, points, therefore, only to an absolutely incorrect system of comparing the various figures and results. Such comparisons are only valuable if each case is considered on its own merits, and the various conditions are as much as possible equal in every case. Then, and only then, have these figures a most convincing and unassailable value. But let them differ in one point only and the comparison becomes a source of error, the more dangerous if drawn by some one who by his profession is supposed to be rather on the other side, and whose divergencies are, therefore, not so easily discovered.

To compare costs of steam winders, with outputs varying between 350 and 3,360 tons per day, and lifting from depths varying between 372 yards and 673 yards, to the same costs of a single electric winder winding from great depths and of an uneconomical type, is, to say the least of it, unfair.

Surely the costs of winding 100 tons of coal depend, in the first place, on the depths from which this coal is wound, and any comparison which does not contain this item has no value whatever unless the depth be equal in all cases.

A second consideration is the cost of the coal used in the boilers. The greater the value (which does not depend on the *calorific* value in most cases) the greater the influence of electric winding.

A third objection is to the method of setting aside a certain part of the generating plant with its own charge of wages and interest for the winding engine, as if the generating station was not used for the total requirements of the colliery at the same time.

The only fair comparison is between the costs in both cases of the *useful H.P. hour*, which, of course, depends on the depth as well.

The generating station should be considered by itself, and this system of comparison includes, of course, the case of a power supply company. A separate generating plant for the winding engine is out of the question, at least in new collieries. In his example of the Zollern

Colliery, Mr. Mountain saddles the winding plant with the cost of one generating set of 1,100 k.w., or half of the total plant installed, while the actual requirements were only 200 k.w. on a total load of about 800 k.w., or a quarter of that load and less than a tenth part of the plant installed. Having obtained the number of useful H.P. hours, either per 100 tons in twenty-four hours or per year, the question is the amount of steam required per H.P. hour in the case of steam winding, and the number of k.w. hours in the power station in the case of electric winding. The first figure can be obtained in Mr. Mountain's examples from the amount of coal burnt per 100 tons wound, and the other figure is either given by the existing power supply or may be easily estimated. The efficiency between useful H.P. hours and units at the balancer terminals in the Zollern winding engine was 60 per cent., and 50 per cent. may, in all cases, be considered normal, so that 1·5 units at the balancer are required per useful H.P. hour on the rope. Moreover, it has been found that this figure does not vary materially with the capacity of the winding engine, and may be taken as correct for four, six, or eight tub winders.

The value of the coal used for steam winding purposes has generally been fixed in a very arbitrary manner. As a rule it will be found that it does not pay to use unwashed slack and dirt in boilers, even putting the value at the very low price of 1s. 6d. per ton. In modern collieries on the Continent and in the States, washed clean coal is used in the boilers, priced at 6s. to 8s., and the slack and dirt are coked in coke ovens or burnt in gas producers. This is a point the writer wishes to impress on the minds of all colliery managers. Unwashed slack and dirt are no proper boiler fuel, however cheap it may seem. It should be coked or used in producers, according to local requirements. Coke-oven gas, and even blast-furnace gas, has also been burnt under the boilers in many cases. To take two extreme cases, the writer proposes to treat the case where the fuel has a value of 10s., and another where the fuel is supposed to have no market value at all. If the point is proved for these two cases, the same may be said for all intermediate fuel values.

Steam Winding.—Taking coal at 10s., the generating costs per ton of steam, including wages, coal, maintenance of boiler-house, interest, etc., are about 2s. 6d.; or, taking 60 lbs. per H.P. hour as a minimum with the best modern engines, about 1d. per useful H.P. hour. With fuel costing nothing, this figure will be about *0·4d.* per useful H.P. hour.

Electric Winding.—Taking coal at 10s., the generating cost per unit in a colliery power station or larger public power supply station (but with much lower load factor), including interest and depreciation, as before, is about 0·4d., or, as we have 1·5 units per useful H.P. hour, 0·6d. per H.P. hour. With fuel costing nothing, this figure becomes 0·2d. As a test we may take the Hulton Colliery with fuel at 5s. 6d. per ton, which would mean 0·75d. for steam generating per H.P. hour, in the writer's calculation, or per 100 tons wound 9s. for boiler-house costs; add 1s. 7d. for winder's wages, and we get 10s. 7d., while the actual

figure was 10s. 7¾d. We can see that, compared on a correct and logical basis with figures taken from *actual* practice in *both cases*, the savings in fuel are considerable and very much more than shown by Mr. Mountain's calculations, based on a wrong application of the otherwise correct figures of steam-winding costs. The winders' wages may, for the present, be taken as equal.

The results of electric winding are given in the case of the Grand Hornu Colliery, which is equipped on the pure 3-phase system, and therefore very wasteful, as the starting and stopping losses are not compensated. This system, which is not now recommended by the makers, should not be compared as a modern electric-winding engine. The fuel consumption given per 100 tons wound is four times as much as even in Mr. Mountain's own calculated example, surely a proof that either the plant must be hopelessly wasteful or Mr. Mountain's figures wrong.

Against this I would like to put two more modern winding engines on the Ilgner system—the Zollern engine and a larger one at the De Wendel Collieries—and compare these results with Mr. Mountain's calculated results. The cost of coal has been taken at 2s. 6d. per ton, having an evaporative power of 7½, while double shifts are worked in both cases.

	Actual: Zollern II. Electric Winder.	Estimate: Mr. Mountain's Case.
Coal wound per day of 8 hours ...	1,350 tons	1,500 tons
Depth of shaft	330 yds.	500 yds.
Weight of coal per wind	4·6 tons	3 tons
Number of winds per day of 24 hours (2 shifts)	521	1,000
Weight of cages, etc.	3·5 tons	3 tons
Time of wind	104 secs.	57 secs.
Maximum speed at present	35 ft. per sec.	36 ft. per sec.
Coal burnt per day of 24 hours ...	5 tons	8·50 tons
Cost of coal burnt per 100 tons wound	6d.	1s. 4d.
Cost of winding plant	£10,000	£10,500
Total cost of proportionate part of generating station	£4,000	£5,700
Wages per 100 tons wound, oil, etc.	11½d.	1s. 4½d.
Total cost of winding per 100 tons ...	1s. 6½d.	2s. 11½d.
Total cost of winding, including interest and depreciation	5s. 7½d.	6s. 11½d.

The winding plant at the De Wendel Colliery cost £15,000 complete, and is doing, at present, 1,400 tons in eight hours from 770 yards. The current supplied from the colliery power station costs, including depreciation and interest, 0·2d. (coal at 1s. 6d. ton) per unit, or per useful H.P. hour at the shaft, 0·3d. This gives us per 100 tons wound, 6s.; wages of winder, oil, etc., 6d.—total 6s. 6d.; and including interest and depreciation on £5,500 (excess of electric over steam winder),

7s. 7½d. Now taking into account that the engine is built for 50 per cent. more output, and is winding at present from 70 yards more depth than in Mr. Mountain's case, his figure for modern steam winding may easily be reached on the full output, and superseded, if one includes stops, rope inspection, etc. At all events it compares very favourably with his estimated 12s. 5d. (See Mr. Mountain's table for electric winding in a similar plant.)

I have only dealt with electric winders on the flywheel balancer or Ilgner system, as it is at present the only system applicable to large winding plant, whether supplied from the mains of a power company or from the colliery power station. In the few cases where the winding plant has its own power station or its own generator plant in the common power station, the figures may be compiled in the same way as Mr. Mountain did, and of course will come out slightly higher, although in the latter case the steam consumption per useful H.P. hour is bound to be somewhat lower (no balancer losses). In examining the results from actual steam-winding plant given in Mr. Mountain's paper we see that, taking into account the probable calorific value of the coal used, the figures for steam consumption vary considerably. This is due to disproportionate banking time, number of hours per shift, etc.

Steam Pressure.—The value given for the coal used varies considerably, although the calorific value of the coal is probably not very different in most cases. This figure, of course, fixed on a more or less arbitrary scale, influences the cost of winding per 100 tons, and it is due to this very low figure at the Denaby Colliery that the costs of winding are so low. Given a more normal value, as in the other collieries, the costs would give truer figures (7s. 3d.), more in accordance with the great depth from which the coal is wound, and with Mr. Mountain's estimate. At the same time, wages and value of plant in this colliery are exceedingly low. The Sherwood Colliery, with quite up-to-date plant and superheated steam, reaches only 50 lbs. of steam per useful H.P. hour, and although winding from less depth during a longer shift, costs come out higher than at most of the other collieries.

These remarks show how difficult it is to draw conclusions from results where all the composing items vary considerably. It is not stated if these results were obtained during a shift or during the whole twenty-four hours, as the actual figures for electric winding. This makes a considerable difference in the results, far more with steam winding than with electric winding. However, even with the latter it varied at the Zollern Colliery from 24 to 29 lbs. of steam per H.P. hour. Given the correct market value for the coal used in the boilers and taken per twenty-four hours, the figures for steam winding will come nearer to Mr. Mountain's estimated figures, which are shown in the last column of the tabulated statement, and as far as possible corresponding to plants of the same output. Mr. Mountain's figures, however, are for winding in single shifts. In both cases the actual results of big electric winders in everyday working conditions have beaten Mr. Mountain's *estimated* figures, both for steam winding and electrical winding, even on his own system of comparison, and without counting

the losses during rope inspection, stops, etc. As already explained, the system of comparison is unfair. The power station costs per unit generated must be taken by itself, including their own interest and depreciation, and only a certain amount per unit should be added representing interest and depreciation on the winding engines of each type. If this system of comparison is followed up, taking the cost of the steam generated in the boiler-house per H.P. hour as the basis in case of steam winding, as we have done in the beginning of this paper, a just and correct basis for comparison is obtained, and our figures from the electric winding engine in actual practice will show up still better. We have taken, however, the official results of the Zollern winding engine as a basis to argue the case on Mr. Mountain's lines, taking into account the interest and depreciation on the *proportionate* part of the power station, so as to leave no loophole for contradiction.

I claim to have shown clearly and conclusively from practical results as well as by reasoning, that the electric winder is in most cases more economical than the steam winder, having regard to the initial capital expenditure as well. Besides this direct economical advantage, there are many indirect savings, such as less maintenance in power station due to steady load, less wear and tear on ropes, greater safety and more flexibility as regards forced pace and overload. Also complete control and supervision of the winding costs is easier, and no overwinding and other accidents need be feared. It is the consideration of these advantages, even if the direct economical savings are not so high at the start, which will decide colliery managers to include winding in the electrical equipment of their collieries, and so to combine the driving power of all and sundry of their various plant in one common power station. For those who are not convinced by the figures and results shown, I beg to treat the question of electric winding, in a few words, on broad engineering lines and principles, without going into figures or details.

Mr. Mountain began his paper with the following remarkable sentence: "When approaching the question of electric winding versus steam winding, it is not desirable to start off at once with the assumption that steam winding is necessarily very wasteful." This is not an assumption, however, but a fact. To my knowledge there is no more wasteful process than steam winding, be it in collieries or in other applications. Electric driving has scored everywhere, and especially there, where intermittent starting and stopping on heavy loads must be dealt with. With even and constant driving the advantages of electric over steam driving decrease quickly, at least as far as mere economy is concerned. A colliery fan can be driven more economically by steam than by electricity, and it requires a cost of from 0·2d. to 0·3d. per unit to make it pay. The same was held for a long time for cotton mills, but in both cases other and indirect advantages have decided the question, not economy alone. On the other hand, electric tramways and railways illustrate precisely the advantage of electricity for intermittent work with heavy loads and frequent stops, and these were, therefore, one of the earliest applications of the

electric motor. Of late, heavy suburban railway work has been successfully attempted with, in most cases, good results, from a commercial and economical standpoint. For the same reason, main-line work with few stops is not considered to offer any advantages for electric working. To a certain extent this class of work may be considered on a par with winding and rolling-mill driving, and in both cases equally good results may be expected, as has already been shown in the results mentioned above. I consider main winding not only a suitable application of electric driving, but the principal and most urgently needed application of electricity to colliery work.

Just as light electric tramway work was followed by heavy suburban railway work, for the same reasons and on the same general principles should heavy winding from great depths be equally well and just as economically driven by electricity as in the case of short depths.

As a corroborating fact of the contents of this paper, I have compiled a list of some forty electric winders at work on the Continent. At the present time over thirty-five electric winders of heavy outputs are being constructed by one firm alone, several being repeat orders. Surely, although it may not be a proof, it must be admitted that those facts do not confirm Mr. Mountain's gloomy conclusions as to the future of electric winding.

JOINT DISCUSSION ON MESSRS. SPARKS'S, MOUNTAIN'S, AND HOOGHWINKEL'S PAPERS.

Discussion at Meeting of March 22, 1906.

Mr. W. C. Mountain: I think the Institution is to be congratulated on the very excellent paper Mr. Sparks has read to us to-night. In my opinion it is one of the most practical papers on electrical work that I have ever listened to, and it also describes one of the most perfect installations of its kind in the United Kingdom. I had the pleasure of going over the installation, and I was struck with the way in which the work had been carried out from the engineering standpoint. I do not think there has been a halfpenny wasted; the buildings are substantial, the work has been well put up, and it is of a simple but thoroughly good character. I think the Powell Duffryn Company are to be congratulated on having had Mr. Sparks to advise them as he has done. Dealing with the paper generally, there are one or two points which I would like to mention. The first is the question of the three units. There are two units of 750 k.w. and one of 2,000 k.w. I have discussed the matter with Mr. Sparks previously, and I cannot quite follow his reason for dividing the units in that way. It seems to me, with regard to the first cost, it would have been less expensive to put in three units of, say, 1,000 k.w. each. Two units would have done the work, and the third would have been a stand-by in case of accident. Of course, as now arranged, if the 2,000 k.w. were fully loaded and then broke down, it seems to me the two 750 k.w. would hardly carry the load. I think in all colliery installations, as a rule, it is advisable to try and divide the generating units into three, and always try to keep the three units the same size, Mr. Mountain.

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for the reason that I have stated. In the ordinary way, two units can be run slightly overloaded to do the whole of the work, or the three units can be run together slightly underloaded, and in case there is an accident, there is a perfect stand-by with two units against anything which may happen. In going over the installation I was struck with the design of the switchboard. Altogether it is an excellent piece of work, and it is a design which for colliery work can be copied, I think, with very great advantage. The next point is the cost per unit. The figure which Mr. Sparks has given in his paper, 0·365d., is, I understand from Mr. Shaw, beyond the actual cost to-day, now that the plant has been more fully loaded. I may say that this cost of 0·365d., from my own experience of colliery work, represents the cost at which current can be produced without difficulty (after making ample allowance for interest and depreciation) in almost any colliery. It will be noticed that Mr. Sparks has taken the coal cost at 4s. 2d. a ton. Many colliery engineers here to-night will bear me out when I say that that is far more than the value of the coal which is usually used under boilers in a colliery. I know many instances where the coal is put down in the costs at 1s. 6d. a ton. It is only put down at that figure because they must put something in, but, as a matter of fact, if it was not used under the boilers it would have to be put on the pit heap, and there, as you all know, it is liable to spontaneous combustion. So that the figure of 4s. 2d. is very ample in most cases. In order to prove what I say, I can tell you that I was at a colliery the other day where they are making 7½ per cent. of small slack in the daily output; 3½ per cent. of that amount is burned under the boilers to raise steam, and the other 4 per cent. is carted away at a cost of 3d. per ton. This leads to my own paper, and shows you the small value of the coal at many of the pits we have to deal with. There is another point to which I should like to refer, and that is the question of lead-covered cables. Mr. Sparks may have had a happier experience with lead-covered cables than I have. In the early days I used lead-covered cables, of course with continuous current; the conditions are not the same as for 3-phase, but I have hardly ever put a lead-covered cable in a colliery which has not sooner or later failed. It is the German practice, I know; I saw them in Germany, but I do not think from my own experience it is good practice. I think lead is best kept out of a pit where there is any moisture or damp, because electrolytic action is very liable to take place, and sooner or later the lead gives trouble. Mr. Sparks has met in a very effective manner the question of driving the haulage gears. I am very glad to see he has adopted slow-speed motors, because from my experience of driving haulage gear, unless the motors are slow speed—I mean a very low speed indeed—the vibration which is set up in the gear sooner or later, with continuous-current machines, breaks down the armatures, and with 3-phase machines it is very liable to damage the rotors. In addition, the wear and tear on the bearings is excessive with high speed, and owing to this there is a possibility of the rotors fouling the stators. The total cost of the installation given in the paper, namely £17 per kilowatt, bears out the figures which I

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have obtained in the contracts I have carried out; and it seems to me to be a very moderate figure for the thoroughly good installation which Mr. Sparks has succeeded in putting up.

My object in writing my paper was to put forward something which should be criticised, because it does not do for engineers to be afraid of criticism. We do not want to pose as electricians; we are members of the engineering profession, and whatever we do has to be approached from the engineering standpoint. The question of electrical winding is one which has received a lot of attention in this country in the last two or three years. The Germans have done a large amount of work upon it, and the work which they have carried out is, I am glad to say from my own inspection (due to the courtesy of the Electrical Company and of Messrs. Siemens), of the very best description. They are jobs which will do credit to anybody, but, in my opinion, they are simply playing with winding. Mr. Markham, who is a maker of some of the largest winding machines in the kingdom, is here to-night. I will not take the words out of his mouth, because he has given me some of his own figures; but when he tells you himself what winding means in this country, you can only characterise the German electric winding plants as electric hoists. Before I approached this subject I had a great many inquiries from different people for electric winding plants, and therefore I was driven to study the subject rather closely. I went out to Germany with the idea of seeing what the Germans were doing, and I have told you with what results. I came back convinced that the cost of electrical winding—I mean the electrical winding gears themselves—was so excessive that there was no possibility of adopting it for serious heavy winding in this country commercially. I therefore set to work to try and get information, with the result that I have prepared the first table which you will find in my paper. This table, I may say, was prepared from information given to me by the twelve firms whose names are on the list. They represent all classes and conditions of collieries in this country; they are not a selected list. As a matter of fact, I put down every figure that I obtained, so that I might compile a table which would fairly represent what may be considered the existing state of winding amongst collieries in this country. Nearly all these tests, or results, were obtained by actual tests made on the engines. Their object was to find out primarily the weight of coal required to wind 100 tons of coal; secondly, the total cost of winding 100 tons of coal without interest and depreciation; and thirdly, with interest and depreciation added at the rate of 5 per cent. interest and 5 per cent. depreciation on the actual cost of the steam engines and boilers. It will be found on going through the table that I have endeavoured to give every possible figure, because I think in a matter of this kind, when we wish to discuss it thoroughly and grapple with it, it is not of the slightest use to try and hide anything. Therefore I have given every possible figure, so that they can be criticised, because it is a matter which requires to be looked into very closely. The last column shows that the cost of winding per 100 tons varies very considerably. There is one cost as low as 3s. 11d. per 100 tons, including

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interest and depreciation—that is No. 7; and in one case it rises to as high as 19s. 10¾d. I maintain that that is the only practical way of considering of the cost of winding. It is of no use talking about so many pounds of steam per useful H.P. on the rope; that conveys absolutely nothing to the mind of the practical mining engineer, and therefore I thought it best to reduce it to the cost of getting the coal out of the pit, *i.e.*, per 100 tons wound. Having obtained these figures, I then communicated with Messrs. Siemens Bros. & Co. and the Electrical Company, London. The latter were kind enough to send me the figures of the Grand Hornu New Mine, which you will find in my paper. Messrs. Siemens also gave me costs of some installations abroad, of which I am very sorry to say I could only make very little use. At the same time, I wish to thank both firms for the kind way in which they met my requests. I then prepared Table No. II., which you will see is based upon the use of high-class compound engines made by Messrs. Fraser & Chalmers. I maintain it is absolutely improper, in dealing with a subject of this kind, to pick out a lot of old obsolete winding engines about the country and compare modern electrical winding engines with them. If we are going to make a comparison, we, as electrical engineers, must be prepared to be faced by what the steam people can do. If you refer to Table II. you will find that I have taken as a standard, first of all, 1,000 tons of coal raised from a shaft 500 yards deep in ten hours per day winding; second, 1,500 tons, 500 yards deep; and third, 2,000 tons, 700 yards deep. The whole of the results in this table are calculated on that basis. The table also gives the size of the engines and the size of the drums; it also states the number and the size of the boilers, and the size of compound condensing engines proposed to be used; it also states the weight of coal used per 100 tons wound, the percentage of coal burnt per 100 tons; and it also gives the cost of the labour, and the men's time, winding, etc. The wages I have divided up so as to show exactly how the total wages are made up. It gives the total cost of winding per 100 tons without interest and depreciation in the last column but one, and it finally gives the total cost per 100 tons of coal wound from the pit, including interest and depreciation. I also got my friends, Messrs. Markham & Co., to give me their figures for high-pressure engines, because it is a disputed point as to whether compound engines or high-pressure engines are the most economical. That is a question which the engineers will fight out; but you will see from the guaranteed results as regards steam consumption that there is very little between the two. I will ask you to note in connection with Table No. III. that it is for winding eight hours, and not ten hours per day. I have therefore made another table (IV.) of Messrs. Fraser & Chalmers' engines for eight hours. A reference to these tables will show how extremely closely they tally. The Fraser-Chalmers' compound engine for ten hours' winding works out at 6s. 3d. per 1,000 tons, 5s. 1½d. for 1,500 tons, and 6s. 6½d. for 2,000 tons, 700 yards deep. Messrs. Markham's figures are 6s. 8½d., 6s., and 6s. 8½d. respectively on the eight hours' winding. If you take the Fraser & Chalmers' compound engines on the eight hours' winding, you will see that

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the cost is 6s. 9¾d., 5s. 5d., and 7s. 2½d. In each of those cases there is 10 per cent. added for interest and depreciation. Having obtained these results, I then set to work to calculate what it would cost to wind electrically, and that is the subject of Table V. I treated that table in precisely the same way as I have treated the steam table, but there are certain figures which have to be assumed. The figure which I have assumed, and which I hope will be questioned, is the consumption of steam per kilowatt. I have taken 25 lbs. of steam per kilowatt-hour, which I consider (on a colliery load which is always varying) is as low a figure as we can safely estimate. One must not delude one's self with a lot of fancy figures which will not be realised in practice. On referring to Mr. Sparks's paper, I am glad to see that he assumes a consumption of 3¾ lbs. of coal per kilowatt, and an evaporation of 7 lbs. of water per lb. of coal, which is a result I have tested and obtained over and over again on colliery boilers—it is very seldom more, and sometimes it is a little less—and I think that may be taken as a fair average figure for ordinary colliery coal. This shows, on that basis, that Mr. Sparks is using 26 lbs. of steam per kilowatt, so that his figure, I am glad to say, practically confirms the figure which I have adopted in calculating the steam consumption in electric winding. Following the table through, it will be found I have taken exactly the same quantity of coal wound and the same depth in each case. As regards the costs of the winding plants, as I was not able to get any costs from the Continental makers, I set to work and made accurate estimates for the whole of these winding gears. I calculated the input into the motor, assuming of course a balancer is used, because I do not think any system of winding I have seen so far is of any use unless a balancer of some kind is adopted to steady the demand made upon the generator or supply station. I have seen the Preussen gear, and it is a very excellent piece of work, but, with all respect to the Electrical Company, I must say I do not think it can be regarded as the most economical way of winding. If we are to wind electrically we must balance our load in some way, and it appears to me that the balancer which I saw at Zollern, which is adopted in other installations, is the only practical way of doing it. I have given all the sizes in this table, but there is a little error with regard to the size of the diameter of the rope; the figure in the tenth column should be $1\frac{5}{32}$ ins. and $1\frac{9}{32}$ ins. I have given the input into the motor, which all can question; I have given the horse-power required on the winding gear; I have given the cost of the electrical plant apart from the generating plant, that is, of the balancer, switch-gear, and the winding gear complete.

We now come to the most serious question of the whole lot, namely, the first cost of the plant. Where, I think, we are going to fall to the ground in electrical winding is the enormous cost of the winding machinery which is required to deal with this work. You see, it raises the total cost straight away, with 10 per cent. added, and assuming 250 days per year (which my colliery friends will tell you are about a fair number of days, when they consider they are doing very

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well), and that in both cases we are working for eight hours per day, the final result is that you get 13s. 9½d. as the cost of the electrical winding per 100 tons wound, with interest and depreciation, against 6s. 9¾d. for the steam winding; 11s. 7d. against 5s. 5d.; and 12s. 5d. against 7s. 2½d. Of course, if we could run our electric winder for twenty-four hours per day it would be a different story; but then, again, it is of no use to argue in that way, because, if you did, the steam engines could also run for twenty-four hours, and you would be no better off; you would come down to the same level again. It seems to me that, if we are going to compete against steam, it is absolutely necessary that we should reduce the cost of our winding plant to something like the cost of the steam plant, and it is for us to try and do this before we can fairly go into the market and say we can compete against steam-engine builders. There is another point I should like to mention, and that is the cost of winding taken at the Grand Hornu New Mine. The Electrical Company were good enough to give me these figures, and they are the only figures that I have been able to get dealing with the matter in a practical manner. I am very much obliged to them for sending me the information, but I am very sorry to say that the figures do not prove our case. Unfortunately, they do exactly the opposite. On referring to Table VI. in my paper, it will be found that winding 1,560 tons in twenty-four hours—which is only about 65 tons per hour, and which I have already characterised as hoisting and not winding—the cost, including interest and depreciation, is 13s. 6d. per 100 tons, against the examples of steam winding which I have given you, varying from 3s. 11d. up to 6s. or 7s. Now I come to another point in connection with the next table, No. VII. This gives the estimated net cost of electric winding, exclusive of electric current, and is, I think, rather rough on the people who are desirous of supplying current from power stations. It will be seen there that I have taken the interest and depreciation on the cost of the winding plant—that is, the balancer, switchboards, winding gear, and motors—and to that I have added what I estimate is the cost for the men's time. The actual cost, viz., the interest and depreciation and the men's time winding the coal, without allowing for the cost of any current at all, comes to far more than the cost of high-class steam winding; and it means that the electrical supply company have to give the current for nothing, and something besides, before they can compete with high-class steam winding. I am quite aware that I have presented a very sorry tale, and I hope it will not be thought that I am a traitor to my profession in doing so, but it is a very serious question. We want to be able to go before colliery proprietors and let them feel that when we do put a thing before them we are telling them honest, straightforward commonsense—that is the reason why I have written this paper.

Mr. Leggat.

Mr. J. LEGGAT: I should like to point out that the figures of the cost of electrical winding in this paper, with the preparation of which I had a good deal to do, are all either estimated or taken from Continental practice. It will be interesting to see whether any results obtained by Messrs. Siemens Brothers for the large winder which they are putting

down in South Wales for the Duffryn Rhondda Company (which will be a good example of English practice) will modify Mr. Mountain's figures at all. The estimated costs for electric winders given in the paper are figured out on the assumption that drums are used and not Koepe pulleys. If these pulleys are used, the whole plant would be reduced in cost by about 10 per cent., and the cost of electrical winding would be reduced accordingly. The paper also only deals with single winders, and the results would be considerably modified in the case of a company having several pits close together, fed from one central station, and especially if the power required for purposes other than winding becomes as great as the power required for main winding. In the majority of cases, however, in this country there will be only one winder, the rest of the power necessary for driving the surface plant, haulage, and pumping not exceeding half the power necessary for winding. In these cases it would be very difficult to bring out the cost of electrical winding better than, or even as good as, steam winding as regards annual cost. In the majority of cases it would be difficult to get colliery companies to spend the extra amount of money which is undoubtedly necessary if electrical winders are put in. There is one way, however, in which these figures can be completely modified in the case of steam winding. The exhaust steam from the winder may be utilised in a low-pressure turbine by means of the system devised by Professor Rateau, utilising the exhaust steam from intermittently running engines. This system is well known, and has been described in papers read by Professor Rateau* and Mr. P. J. Mitchell before the Institution of Mechanical Engineers and the West of Scotland Iron and Steel Institute. Take the case of a winding engine using 450 lbs. of steam per wind, and winding 60 times per hour, and exhausting to atmosphere. Allowing 20 per cent. for condensation in the engine, cylinders, pipes, etc., it gives 21,600 lbs. of steam available for the low-pressure turbine, and, with a consumption per E.H.P. per hour of 30 lbs., a total of 720 E.H.P. is available for driving motors on the surface and underground. In most cases this is amply sufficient for all purposes about the pit, with the exception perhaps of driving the fan. Similar results have been obtained in several collieries on the Continent, and have been guaranteed in the case of two or three plants being installed in this country, no extra back pressure being put on the winding engines. The heat accumulator, which may consist, as described in the papers referred to, of an old boiler, is made large enough to keep the turbine going at full load during the ordinary stops of the winder. With a 500 k.w. plant installed at the steel works of the Steel Company of Scotland, stops for periods as long as six minutes are being successfully negotiated. If the stops are longer than this, a special automatic reducing valve comes into operation, passing live steam through from the boilers. Professor Rateau states that he can with this system give as much as 7 ins. of vacuum on the winding engine exhaust if necessary, and still guarantee a consumption of not more than 36 lbs.

Mr. Leggat.

* *Proceedings of the Institution of Mechanical Engineers*, June, 1904, p. 771.

Mr. Leggat. of steam per E.H.P. per hour, with a vacuum on his condenser of 27 in., although he can considerably reduce this consumption if a back pressure of, say, 10 to 12 lbs. per sq. in. above atmosphere on the winding engine exhaust can be permitted. Where results like these are obtained, the steam passed through the winding engines is used very economically indeed, and the case for steam winding as against electrical winding is much improved.

Mr. Markham. Mr. CHARLES P. MARKHAM: The big winding engines that we are building to-day are of such a size that I do not think it would pay any colliery company to put down their equivalent in electrical machinery. In the first instance, we cannot sink a pit at a cost much under £200,000, because in the South Yorkshire districts we are now going down to a depth of between 800 and 1,000 yards. To do any good, we must raise 5,000 tons a day—between 4,000 and 5,000 tons a day is now a common quantity in South Yorkshire. We have to get the men in and the muck and the coal out in eight hours' work. We want an engine there that will develop enormous power of steam for about two revolutions, getting the acceleration up to a very high point, then cutting off to practically zero and running out at the pit top. We are making windings there now with engines having 48-in. cylinders, 7-ft. 6-in. stroke, 120 lbs. of steam behind them, and full steam for the whole stroke; making two revolutions cutting off at seven-eighths, or two and a half, and then cutting off at one-tenth for about another ten revolutions; and by that time they are accelerated sufficient to run them out at the top. The balance rope that is generally used now pulls the engines quietly up to rest on the props; and in a pit having a depth of 800 yards they will make from 62 to 68 windings per hour. These little electrical hoists are simply child's play. The dead weight, or the dead pull on the rope and on the drum, is 21 tons; they wind twelve tubs of coal with a cage weighing about 8 tons, and the bull chains weighing about 5 tons; and they wind that weight up at about 1,200 to 1,500 ft. piston speed. I fail to see how electrical energy at the present time is going to compete with these engines. Roughly speaking, the steam engines cost £5,000 to £6,000 without boilers. The boilers are practically the same in every case. If you want the power and are boiling water, it does not matter whether you use it direct in the steam engine or whether you go a roundabout way with it and put it into an electrical engine. I think the remark made by the last speaker is about the best thing you can do—to turn the steam into a Rateau turbine afterwards, and to work the rest of your power at the colliery by electrical energy. There is another system which Mr. Mountain has referred to in his paper, which I think myself is far preferable to the tail-rope system, namely, the conical drum. The conical drum at Cadeby is the most economical winding apparatus, in my opinion, in Great Britain. The engines have 45-in. cylinders and a 7-ft. stroke, and they are working there constantly on a range of eight boilers, with 80 lbs. of steam pressure, I think it is. I believe only six of the boilers are working, and they are there winding out of the pit from 3,000 to 4,000 tons a day.

Mr. T. CAMPBELL FUTERS: As one who is greatly interested in colliery work, having had charge of the machinery as a colliery engineer, this question of electrical winding is, in my opinion, one of very great importance. I do not believe in the argument used by some engineers on this question, that colliery managers as a rule are rather loth to take out their old steam engines on account of their being so used to them that they do not care to part with them. I do not believe that is true at all. I quite believe that colliery managers and colliery engineers would be very glad indeed to turn out their old steam engines and adopt electrical winding, provided they can be convinced that the electrical winder would be very much more economical to them than the steam winder. In the main, however, I am bound to agree from my experience with what Mr. Mountain has already said. The great question affecting electrical winding is that of cost. When one considers that the cost of electric winding, as at present arranged, amounts to something like £10,000 to £15,000 for the winder alone, when an excellent steam winding engine can be bought for something like £5,000, it is quite evident that any colliery company will regard the greater outlay of capital as a very serious item. Another point that has been made very much of, in regard to electrical winding, is the question of automatic safety appliances. In this country the colliery manager looks with very great suspicion upon these things. As a rule, safety appliances are not in favour in this country. If we, as electrical engineers, go to the colliery manager and say to him: "Here is an electrical winder that can be absolutely safely worked by one man without the use of any electrical accessories or safety appliances," there is no doubt he will consider the matter much more favourably; but if we make a point of these electrical automatic safety appliances, he will look towards it as being a point tending to weakness of the machine itself. Another point that has been raised is the great steam consumption of ordinary winding engines. No doubt the ordinary winding engines, especially in the North of England, are very great steam eaters, but you must remember that they are very simple. They are controlled practically by two handles, one controlling the steam regulator, the other for reversing, and will run for years without costing a penny for repairs. Although they are not at all economical in the consumption of steam, they can be improved by putting on better valve gear, and, depending upon the complication of the valve gear, very good results can be obtained. There are, I believe, at present working in South Wales steam engines which only use 26 lbs. of steam per indicated H.P. per hour, and further there are compound steam winding engines which only use something like 52·2 lbs. of steam per *useful* H.P. per hour. These latter engines are working without either expansion or condensation, and if we consider the greater advantages which might be obtained by using expansion and condensation, which would probably save another 10 to 15 per cent. of steam, we can see that the advantages, when the capital expenditure and cheapness of the fuel are considered, are greatly in favour of the steam winder. There is, of course, to be considered the greater efficiency of the electrical Mr. Futers.

Mr. Futers. plant, but against that we have the greater cost in capital expenditure, which, as Mr. Mountain has pointed out, runs the working costs up to more than what the saving in coal amounts to. It is a very difficult matter to compare ordinary steam winding engines when you take the amount of steam consumed as *per useful H.P. per hour.* So much depends upon the weight of drum, type of cage guides, the head gear pulleys, the arrangement of the decking, depth of pit, balancing, and all that kind of thing, which vary considerably at individual collieries. If it were possible to attach electrical winding plant on to the steam drums by simply removing the engines and putting a motor on each side of the drum, every other condition remaining the same, it is a question to my mind whether there would be any very great saving in steam consumption, when you consider you have to pass the energy first through the dynamo, then through the motor generator, and lastly through the motors of the winding drum. I do not think it would be possible to gain probably more than 5 to 10 per cent. saving in steam consumption. It was thought to be an improvement in the right direction when the spiral drums were introduced, but I cannot agree with what Mr. Markham has just said, as it can be easily shown that owing to their great weight—sometimes as much as 80 tons—they consume more energy than they save. Again, it is a mistake to assume that a light load raised at a high speed is economical either in working cost or capital expenditure. The large winding plants installed in Germany, it is important to notice, are all fitted with the Koepe pulley, which necessitates the use of a counterbalance rope. This system, however, has not found favour in this country, as it is not suitable for high speeds, owing to the tendency to slip, and further because of the ever-present danger that if the rope broke both cages would fall to the bottom of the shaft. By using what are known as safety ropes this danger can be removed, but only at the expense of causing the system to lose its feature of simplicity and cheapness. I think Mr. Mountain has done a real service, not only to the mining section of the engineering profession, but also to the electrical profession, by what he has said, because, by looking at this matter fairly and squarely, we see exactly what is wanted. If electrical winding is to win, there is no doubt, as Mr. Mountain has already stated to-night, that we will have to improve the electrical winder, and so reduce the initial cost that it can compete in that item very favourably with the steam engine. There is no doubt there is a great future before electrical winding if that can only be carried out.

Discussion at Meeting of March 29.

The President. The President: I think Mr. Mountain desires to make a statement with reference to one of his tables before the discussion is resumed.

Mr Mountain. Mr. W. C. Mountain: In the examples which I gave for electric winding compared with steam winding, it has been pointed out to me that the prices included in my estimate for the boilers in electric winding are more than in the case of the boilers for steam winding. Of course that price includes the price of the boilers with steam pipes,

feed pumps, and a proportionate amount for the condensing plant. The figures which I have given are based on condensing engines for electrical winding and high-pressure engines for steam winding. I thought it might perhaps save those figures being wrongly discussed if I gave you the information. It should have been stated in the paper. I would like, as an extension to Table I., to add the result of a test which I have had made by running the winding engines at North Seaton Colliery for a whole week from separate boilers. The figures are as follows :— Mr. Mountain.

North Seaton Winding Engine.

Vertical Single-Cylinder Condensing Engine, about 45 years old.

Cylinder, 60 in. by 84 in.
Steam pressure, 20 lbs.
Revolutions per wind, 11¾.
Drum, parallel type, diameter, 21 ft., 6¼ in.; width, 4 ft. 3½ in.
Rope, 4½ in. circumference; weight, 1 ton 5 cwt.
Weight of cage and chains, 1 ton 15 cwt. 1 qr.
Tubs, 4; weight, 1 ton 9 cwt.
Depth of shaft, 260 yards.
Weight of coal per wind, 2 tons 8 cwt.
Time for banking, 15 to 18 seconds.
Time for total wind, 50 to 56 seconds.
Hours per shift, 11 (including 2¼ changing men and waiting on).
Winds per hour, 42·5.
Winds per day, 468 (coal drawing).
Coal per day, 1,150 tons.
Coal burnt per day, 11 tons 10 cwt.
Percentage of coal used to coal wound, 1 per cent.
Value of coal per ton, 2s. 6d.
Wages: Winder, 7s. 1½d.; stoker, 4s. 4d.; ashmen, 2s. 2d. per 11 hours, including house-rent and fire-coal.
Wages per 100 tons wound, £1 2s. 2d.
Oil and stores per 100 tons wound, 4s. 6d.
Cost of coal per 100 tons wound, 2s. 6d.
Cost of engines, say, £3,000 } estimated.
Cost of boilers, say, £1,600 }
Interest and depreciation on engines at 10 per cent., £300; boilers, £160.
Working days per year, 250.
Interest and depreciation on engines per day, £1 4s.; boilers, 12s. 9½d.
Interest and depreciation on engines per 100 tons wound, 2s. 1d.; boilers, 1s. 1½d.
Total cost per 100 tons without interest and depreciation, 4s. 0·8d.
Total cost per 100 tons with interest and depreciation, 7s. 3·05d.

This engine, which is forty-five years old, is practically as good to-day as it was when it was put down. I thought I would give you these figures, because they are the result of a test running for a week. The

Mr. Mountain. boilers were set aside for the test. I want you to understand that the coal consumption is not estimated, but all the figures were obtained by special tests.

It is very extraordinary that, although there have been several newspaper notices saying that I have overestimated the cost of electrical winding and have underestimated the cost of steam winding—which I do not think is correct—only last week in Newcastle Mr. Hooghwinkel produced some figures of the Zollern plant, in which he said that the plant, which, as a matter of fact, is capable of winding something like 1,200 tons 330 yards deep in 8 hours, cost £10,000, against my estimated figure of £10,500 for a plant to wind 1,500 tons a depth of 500 yards in the same time, so that you see there is not a lot to quarrel about; and I have really given a lower estimate. Then he gave another estimate of the plant of the De Wendel colliery, where they are winding 1,400 tons from 700 yards deep, and the cost of that plant, exclusive of generating machinery, he put down at £15,000, against my estimate of £14,200 for plant to wind 2,000 tons 700 yards deep. That pretty well confirms my figures, and they are useful figures to have, because they prove whether I am right or wrong. The net result of the whole of my figures is given in the last column but one (Table V.). I show that the cost of winding per 100 tons, 500 yards deep, and 1,000 tons per day is 3s. 8½d. without interest and depreciation; 1,500 tons per day, 500 yards deep, costs 2s. 11½d. per 100 tons without interest and depreciation; and 2,000 tons per day, from 700 yards deep, costs 3s. 0½d. per 100 tons, also without interest and depreciation.

Mr. Hird. Mr. F. Hird: In the first place I should like to add my tribute of thanks to Mr. Mountain for the very valuable information he has accumulated with regard to the performance under actual working conditions of so many steam winders. The information which I refer to is chiefly contained in Mr. Mountain's Table I., and it would no doubt have been still more valuable if we knew a little more as regards the exact conditions under which the plants were operating when these figures were arrived at. Mr. Mountain, in his remarks to-night, has to some extent supplied this in stating that most of them have been taken with the boilers isolated for the test. Turning now to Tables IV. and V., it appears to me that it is implied, if not stated, that the chief comparison between steam and electric winding is to be taken from these tables. On that point I should like to remark that there are certain inaccuracies in Mr. Mountain's figures which raise considerable doubt in one's mind as to the value of the results obtained. On one of these apparent inaccuracies with regard to the boilers Mr. Mountain has given us some explanation to-night, but one would like to know why it is necessary for the cages to be a good deal heavier in the case of electric hoisting than is necessary in the case of steam winding. Again, the rope is a good deal heavier for the electrical installation, which may be partly due to the greater acceleration which is provided for in the case of electrical winding; but it is not clear why such very high accelerations have been selected. They certainly have had the effect of making the electrical plant bigger than would

otherwise have been necessary, and so increasing the capital outlay, which forms the principal point against electric winding. I will not insist any further upon these points, because I believe they will be fully dealt with by others who are more competent to speak on the question than I am; but I would like to draw attention to one phase of the matter which, to some extent, has been suggested by Mr. Hooghwinkel, and that is the very great difference there is between the results obtained from actual steam winding and the estimated results to be found in Table IV. The whole comparison, I submit, is entirely misleading, because it is not fair to compare the electric winding engine with the estimated figures for steam winding. It may be urged, of course, that the figures for the electric winding in Table V. are also estimated, and that therefore the comparison is fair, but there are some very good reasons for discriminating between the two cases. Those reasons I touched upon for the first time in a paper which I read before the Institution of Mining Engineers respecting electric winding in 1903, and, although that is rather a long time ago, I see no reason to change the opinion which I then expressed, which is to this effect: That the difference between the steam consumption under ordinary working conditions and the steam consumption under test conditions is enormous. This is not merely a pious opinion, but it is the result of actual figures and tests which have been taken in the most careful manner. On the whole, one may say it is a very fair statement to make that, under ordinary working conditions, the steam consumption is 100 per cent. higher, or thereabouts, than under the test and guaranteed conditions. The reason for this is not very far to seek. In the first place, in most if not in all steam winding engines, the distribution of the steam in the cylinders is left to the control of the man in charge. I think that fact in itself will appeal, at any rate, to central station engineers. Let them conceive of running their engines, not with the valves set in the way which is the result of the experience gained in years of steam engine practice, but left to the operation of a man. The result can be imagined. Unless the man is a past-master in thermo-dynamics, and pretty nimble too with his hands, the result must necessarily be a very great waste of steam. That is one reason. The next one is that it is possible—in fact, very easy—to lose a large percentage of the whole energy which is required for the lift during the braking operation. It is quite easy to do that and to know nothing about it when you are working with steam, whilst the conditions under which electric plants are operated are such that the braking can only be done by paying back energy into the motor generator. There can be no loss of power in braking except when the emergency brake is used, and the emergency brake, of course, is very seldom used. There is a third source of loss, too, inasmuch as at the end of a wind it is common for steam to blow off through the safety valves. That is a result to be expected, because the boilers are usually worked up pretty high, and when the lift stops the steam has to go somewhere, and it goes into the atmosphere. That steam is not included in the guaranteed figures which are given by engine-makers for the purpose of these Mr. Hird.

Mr Hird. comparisons. When all this is taken into account, it explains the fact that we find an average figure of 90 lbs. of steam per effective H.P. in the shaft, taken from Mr. Mountain's own figures in actual tests. I would like to make one short reference to the plant at the Grand Hornu Mine, of which Mr. Mountain has given particulars. I should like to point out that on this unfavourable result, which may have contributed to lead Mr. Mountain to his somewhat pessimistic conclusions, there are several points to be observed: first of all, that the amount of coal raised per hour is very small; that the depth is very great, both of which are unfavourable conditions; and the working takes place on what we may call a rheostatic control, which is extremely wasteful, and not one which should have been used in making a comparison. It is rather regrettable that attention was not drawn to the fact that this was the case, in view of Mr. Mountain's expressed opinion that the only electric winding plants which are worthy of any consideration are those which provide for a storage of power and balancing arrangements. In conclusion, if I may express a personal opinion, it is to the effect that electric winding is coming, or in fact has come, to stay. I think there are good reasons for this, for, whatever one may think about winding plants, we are all agreed that most of the other machinery about mines and collieries ought certainly to be driven electrically, and once that opinion is held and acted upon by colliery and mine owners, we shall find that they will not be long in perceiving the inconvenience, apart from any question of economy, of having an isolated steam plant merely to do one operation. This is a thing which is bound to have a great influence, and I think it behoves us, as electrical engineers, to be prepared for what must inevitably come, and that is a large demand for electric winding plant—a demand which may shortly attain something of the dimensions which it has already reached on the Continent, where, as Mr. Hooghwinkel has already told us, one firm alone has in operation, or in the course of construction, forty-five winding plants, some of which are certainly not to be described as toys, but are quite comparable in magnitude and in every other respect with the very biggest things which have been done in steam winding.

Mr. Addenbrooke. Mr. G. ADDENBROOKE: I feel some diffidence in speaking, because my idea was to take up this question from a point of view quite different from that of previous speakers. As one of an old family of colliery proprietors, and one whose misfortune it has been to be a colliery proprietor in a small way most of his life, I have had to look upon this subject rather from a financial than from a technical point of view. Mr. Mountain has done a great service in putting this problem of winding clearly before us. However, coming to the particular point of view from which I regard the subject, it will be noticed that Mr. Sparks in his paper deals with the costs of supplying the energy for the plant he has put up, and from his closing remarks it looks as though he thought it would pay only a smaller colliery company to take their supply from a power company, and Mr. Mountain in his paper alludes to the power company in very indefinite terms; I thought, therefore, it might

Mr. Addenbrooke.

be perhaps worth while to put on record in the discussion on these papers the sort of results which I think power companies ought to be able to arrive at. In the case of winding, which forms the subject of Mr. Mountain's paper, the load is extremely intermittent. I see that in the discussion at Manchester Mr. Braun gave a diagram (p. 546) which is a little difficult to follow at first, but which gives an idea of what the load factor of these colliery winding plants is. It has always struck me that the load factor of these winding plants was a good deal like the load factor of an electric tramway. It is very well known to tramway engineers that a tramway with one tram on it practically needs 50 k.w. of generating plant to run it; but with a large system with many trams, about 10 k.w. in the station per tram-car will do very fairly. The winding diagram here is exactly of that sort. To put up electric winding for one colliery may or may not be a thing worth doing. It is really, from the colliery owner's point of view, a question of finance. A good deal more must be spent on the electric plant in order to attain a lower steam consumption. It does seem to me that here is one of the openings for a power company. In a particular area, for instance, with which I am dealing now, there are within a radius of four miles about thirty collieries belonging to twenty different owners. In such a case, it appears to me that, by putting those collieries on to a power company's station, an enormous saving will be effected in the amount of plant that is required to supply the energy for the winding engines at the generating station, because, just as happens in the tramway, the maximum loads will not coincide. The point next comes, What are the sort of figures that power companies could supply such a load at? Power companies hitherto have been under a great many disabilities. I do not think that those who are outside really grasp the immense amount of work that has to be got through to put them on their legs. Local authorities are not very conversant with these matters, and they all have an idea that they may give something away or let themselves in in some unforeseen manner; and if it is possible to put in a series of restrictions in agreements which are exceedingly hampering and useless, one may be pretty certain it will be done. All these things are not conducive to the financier finding large sums of money readily for starting undertakings of this sort; consequently it has happened that nearly all the plants in this country have been started on much smaller scales than the promoters originally intended for carrying out their original objects. Now, there is nothing outside ordinary engineering in a power company. The position is simply this, that by working on a large scale you get cheaper generation than by working on a smaller one, and that having cheaper generation and also better load and diversity factors, one can afford to spend a certain amount on transmission. As the transmission mains get longer, this advantage diminishes and finally vanishes. Most of the power companies in the early days, and even up to the present time, have been greatly hampered by their Parliamentary costs, by the difficulties of raising money, by the fact that they had to spend large amounts of money for a small amount of work, and consequently they

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have not been able to quote such prices as in many instances would enable them to get a large load readily. Now, I have, for the purposes of my own practice, for some time been accumulating figures as to the relative prices at which power companies could supply, supposing they had a fair chance, supposing they were really able to put down large stations and get at their work in what one may call an ordinary engineering manner. These figures are embodied in some diagrams which contain a set of curves giving the prices of supply from a power station of 3,000-k.w. size, and going up to a size of 60,000 k.w.

I have taken 60,000 k.w. as the maximum, simply from the fact that

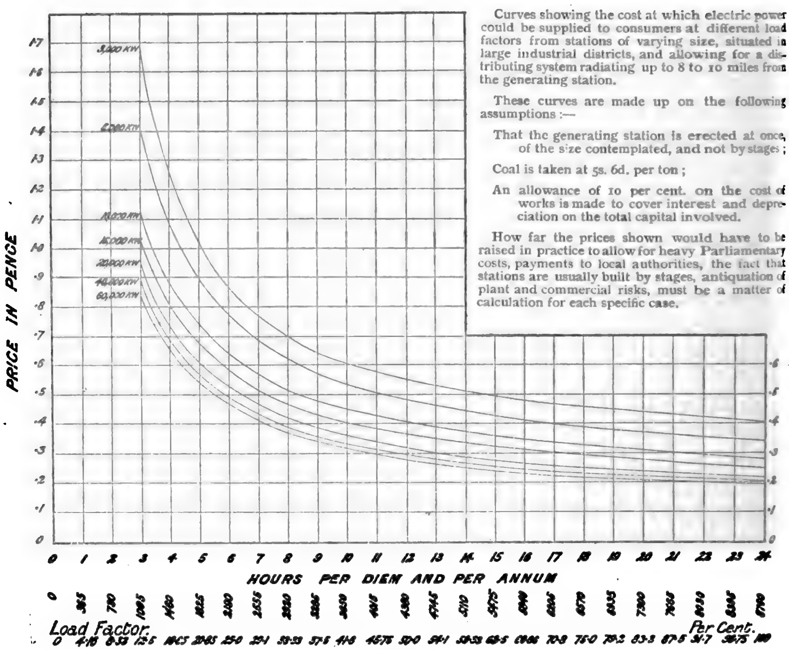

FIG. A.

it was the size of station for which Mr. Merz got out figures in the Administrative County of London Bill last year, and those figures, I think, were not seriously criticised by any one, at any rate for the generating station. The mains in the table are worked out on the basis on which they would be required in an industrial district in the country outside great towns. Starting with 3,000 k.w., there are curves for 5,000 k.w., 10,000 k.w., 15,000 k.w., 20,000 k.w., 40,000 k.w., and 60,000 k.w.; one of the objects in drawing up these curves was to find out how far economy was gained by increasing the size of the station.

To come now to Mr. Sparks's conclusions in his paper, he states that he is supplying at 0·36d. per unit, making an allow-

ance of 10 per cent. on the cost of his work to cover interest and depreciation of the capital involved. It curiously happens that, in order to put the matter into a simple form for these curves, I had assumed exactly the same figure for interest and depreciation. Of course, a power company is, unfortunately, not like a colliery company; it has to get Acts of Parliament and various other things which are very costly, and in the early years there is a considerable percentage of capital expenditure which must be added to the actual cost of the works themselves; but I think the power company would raise its capital at a lower figure than a private company or person—at any rate, it could do this as soon as it was on a working basis. I see from these curves, taking 37 per cent., which is about Mr. Sparks's load factor, that if they had a station of about 20,000 k.w., it would enable the power company to supply at an equivalent price to that shown in Mr. Sparks's paper, up to, say, eight or ten miles from the generating station, and that with a generating station of 40,000 or 60,000 k.w., that figure would again be very considerably improved on. As a matter of fact, in the districts in which the Powell Duffryn Collieries are situated there is probably, from a given spot there, within a range of seven or eight miles, over 100,000 H.P. used in collieries, and therefore it would be quite easy to put up a 60,000-k.w. generating station. The same reasoning applies in many other places, and, consequently, I think there is probably a better opening for electric winding than Mr. Mountain apparently imagines, if the current is supplied from power companies; and I also think that perhaps the scope of power companies, when once we can get down to a real engineering basis, is larger than the authors of the papers would lead us to suppose. Mr. Addenbrooke.

Dr. R. HERZFELD: So much has been said in favour of electric winding engines that I think the opposition which has been raised by Mr. Mountain is only natural, and it is also welcome as far as it elucidates the problem. But I am afraid the figures that Mr. Mountain gives are so favourable for steam winding that the suspicion must at once arise whether they are right. I cannot criticise the figures given for the steam winders, but those given for the electrical installation which have been quoted against them are not quite correct, and have already done some considerable harm, as two gentlemen this evening have stated that the Grand Hornu installation is wasteful, one of them having gone so far as to say that the system adopted at the Grand Hornu has been discarded by the makers. I should very much like to know on whose authority this statement has been made. It is not a wasteful installation, and, as I shall prove, it comes out better than the ideal installation of Mr. Hooghwinkel, who said that 1·5 k.w. are wanted for each horse-power hour in mineral raised. Dr. Herzfeld.

I propose to traverse the statements in Mr. Mountain's paper. He says in Table VI. that the total cost of winding 100 tons at the Grand Hornu mines is 19s. 7¼d., as compared with an average, as I make it, of 9s. 8d. for twelve steam winders given in Table I. As a matter of fact, as previous speakers have already said, it ought to have been stated that

Dr. Herzfeld.

the average depth of the twelve representative collieries is 435 yards, while the depth of the Grand Hornu is 767 yards, or nearly double. But this is not the only objection to Mr. Mountain's figures. If it were true that the cost of winding 100 tons were 19s. 7¼d., I think electrical engineers would at once give up the battle; but, unfortunately, there seems to be a misapprehension. Mr. Mountain mentions in his paper that, from the communication received from the makers, the total cost of generating energy at the Grand Hornu mines is £13 14s. 6d. per day, for which amount 16,000 units are generated. Mr. Mountain seems to be under the impression that these 16,000 units are used for the winding engines alone, but there are various other apparatus which draw on this supply. For instance, there is a 125-H.P. pumping motor, two 200-H.P. ventilating motors, a locomotive plant, screens, and other accessories, amounting altogether to more than 1,000 H.P. In order to arrive at a figure which actually represents the consumption of the winding engines at Grand Hornu, Mr. Mountain ought to have consulted page 37 of the document furnished to him by the makers, where a curve is given of the actual requirements of the winders. Two winders are at present working at Grand Hornu, which raise 1,400 tons a day from a depth of 767 yards, and this represents a total of 3,640 H.P.-hours in mineral raised. From careful investigation with recording wattmeters (the curves are given in that communication), it has been found that 1 H.P.-hour in mineral raised draws 1·46 units from the generating station—on the strength of that Mr. Hooghwinkel may possibly correct his statement—so that the total consumption of two winding engines is 5,315 units per day, instead of the 16,000 that Mr. Mountain attributed to them. The result is that the sum of £13 14s. 6d., which, according to Mr. Mountain's figures, is the total cost of winding per day, is reduced to £4 11s. 3d., and the 19s. 7¼d. per 100 tons raised is reduced to 6s. 6d. This point is very much the most important of all I wish to say, but there are some other little points that I wish to remark upon, and I will shortly mention them. Mr. Mountain says that this unfavourable result —I suppose he will now call it a favourable result—is only attained by working twenty-four hours a day. I have some information that the winding is done in seven hours. The other points are minor ones compared with these, and have been partly dealt with by previous speakers. I may add that I think with an electric winding installation the boiler plant works out smaller, not only because less coal is burnt, but also on account of the steadier load of the boiler plant, because there are excellent means of balancing every peak in an electric plant which must be provided for in a steam plant.

If I may be allowed to refer to the discussion also, I should like to mention one point that Mr. Markham laid special stress upon at the last meeting, namely, the acceleration. He said electric winding would have very difficult problems to solve, because steam winders were ever so much better for the acceleration of heavy masses. I think the problem of acceleration in winding is not nearly as difficult as the problem of acceleration with reversing rolling mills, and it may interest Mr. Markham to know that lately five huge rolling mills have been

converted for electric driving, which reverse ten to twelve times per minute, and have an average driving capacity of 10,000 to 14,000 H.P. Compared with these the electric winders are toys, as Mr. Mountain says. Electrical engineers know well enough that the latest development of continuous-current dynamo design allows for practically an unlimited amount of current to be taken out of the dynamo with low voltage, so that the acceleration problem does not require any new development. The electric driving of these rolling mills was decided upon, not on account of any saving in the coal-bill, but in order to increase the output of the rolling mills, or what amounts to the same thing, for the better and more energetic acceleration obtainable by electric motors. Dr. Herzfeld.

Altogether, I think the opposers of electric winding must come with heavier guns if they want to check the progress of electricity.

Mr. A. S. CLIFT: It is quite true that in most instances the first cost of a steam winder is less than that of an electric winder, but, on the other hand, I think it will be admitted that the electric winder is more economical as regards steam consumption than the steam winder. Therefore if coal costs nothing, winding by steam would be cheaper, and if coal is valuable, winding by electricity would be cheaper. There is some coal value at which the two systems are about on a par, and I think it would be of possible interest to you if I tried to show you where this point occurs: and to do so I will use some of the data which were handed to Mr. Mountain by Messrs. Siemens Brothers. A part of these data is shown in Table A. The result of the twenty-four hours' test under ordinary working conditions was that the steam consumption at Zollern during the main working shift was 26 lbs. Throughout the whole twenty-four hours the average steam consumption per H.P.-hour in the shaft was only 31¼ lbs. Table B. shows for the eleven collieries listed by Mr. Mountain the total effective H.P.-hours in the shaft, and the calculated steam consumption per effective H.P.-hour in the shaft, based on 7 lbs. of steam per lb. of coal, which is the figure that Mr. Mountain mentioned at the last meeting as a fair average. In Table I. of Mr. Mountain's paper he only refers to the figures given for the Hulton Collieries as having been obtained under actual tests. As the figures of steam consumption vary very considerably, I think it would be of interest if Mr. Mountain would kindly tell us in which of the collieries the boilers were isolated, because it is only by this means that the amount of coal which is properly chargeable to the winding engine can be ascertained. Mr. Mountain has criticised the use of the figure giving the amount of steam per effective H.P.-hour in the shaft, saying that it does not convey much meaning to the average colliery manager. This has not been my experience. I believe that colliery managers appreciate exactly what this quantity means. It is really the true measure of efficiency of any winding engine. It is better than taking the coal consumption, because the uncertain quantity of the evaporative capacity of the coal is thus eliminated. In the same way, the effective H.P.-hours in the shaft per day are the true measure of the capacity of a winding engine. Upon those two Mr. Clift.

Mr. Clift. sets of figures comparisons really should be based in order to be fair. I should like to refer to Mr. Mountain's Tables IV. and V., in which he compares steam engines with electric engines. In the first part of his paper Mr. Mountain points out the advisability of choosing a long period of acceleration in order to reduce the peak load of a winding engine. That applies equally to a steam winder; but it will be noticed that he gives in Table V. for the electric winder the very small period of acceleration of six seconds for the second case and nine seconds for the first case, while the corresponding period for the steam winder in one case is more than double. It seems to me that is unfair to the electric winder, because under these circumstances its peak load must be very much greater than it need otherwise be, and the cost of the installation will be unnecessarily increased. In Table V. the rates of acceleration and retardation are the same, but the periods of acceleration and retardation are different, which is a physical impossibility. Taking the figures for the maximum speed of the steam winder and the time of acceleration, of full speed run and retardation, and working them out, it will be found that the first steam winder, listed in Table IV. as winding from 500 yards, will only, according to these figures, wind from 319 yards; the second winder will only wind from 350 yards instead of 500 yards; and the third winder will only wind from 400 yards instead of 700 yards. The time for changing trucks given for the electric winder is very much longer than for the steam winder, which means that the electric winder has less time in which to accomplish its wind, and must be made correspondingly larger and more costly. In order to draw up what appeared to me to be a fairer comparative table, I have taken Mr. Mountain's figures for the third case and reproduced them in Table C. The figures for the steam winder have been left practically unchanged; about the only difference made for the steam winder is in the amount of coal burnt. Mr. Mountain gives a figure of 13 tons for this steam winder. I imagine that this table may have been drawn up by the makers of the steam winder. They would naturally make it appear as favourable to the winder as possible, and they have apparently assumed an evaporative capacity of 10 lbs. of steam per lb. of coal. At that rate it is possible that 13 tons of coal would drive the winder under test conditions. Taking the same evaporative capacity of coal for this steam winder as has been taken for the electric winders in the lower table, namely 7 lbs., the amount of coal would rise to about 19 tons. In order to make the figures what would seem to be a fair average comparable with the average figure of 30 lbs. of steam (per H.P.-hour in the shaft) which I have assumed for the electric winder (not the lowest possible figure, which would be about 24 lbs.), I have given the coal for the steam winder as 20 tons. I think that is very fair to the steam winder—if anything, perhaps too fair. The result of the table is stated in the last column, and the figures differ considerably from those given by Mr. Mountain. I have plotted my results in diagrams to show them more clearly. In Fig. B the black line indicates the cost of winding with a steam winder at different costs of coal. The dotted line shows the corre-

sponding cost of electric winding. The two lines cross at about 3s. Although calculated quite independently, the figure which Mr. Hooghwinkel gave for the cost of winding at De Wendel, which is a plant corresponding in size, falls on the dotted line of Fig. B. In order to have another check, I have worked out an electric winder which is of the same capacity as one of the Hulton Colliery winders. I believe Mr. Clift.

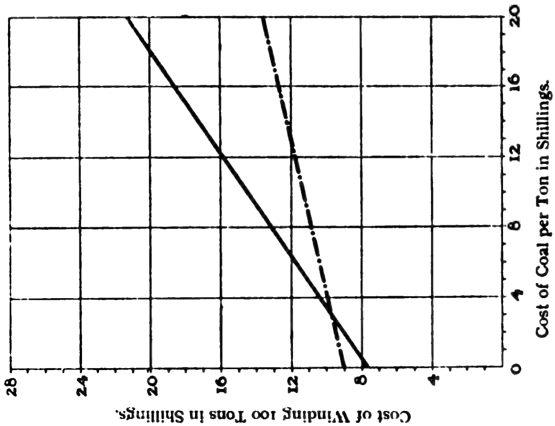

Fig. C.—Engine Winding 567 Tons of Coal in $7\frac{1}{4}$ Hours from a Depth of 312 Yards.

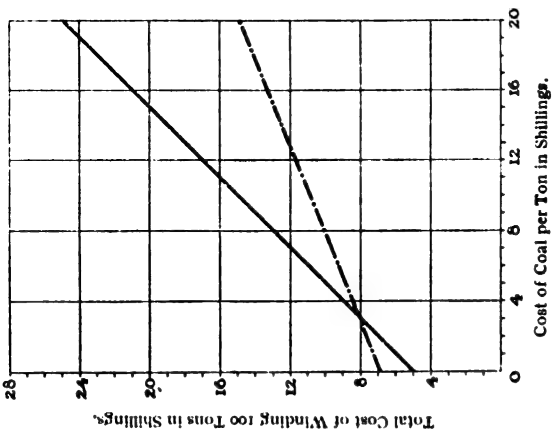

Fig. B.—Engine Winding 2,000 Tons of Coal in 8 Hours from a Depth of 700 Yards.

Black line indicates cost of winding with Steam Winder.
Dotted line indicates cost of winding with Electric Winder.

it is the first winder, the one which is working under rather better conditions. I selected the Hulton Colliery winder because it is one which Mr. Mountain marked in his table as having been actually tested. The result is shown in Fig. C, and it will be seen that the lines there cross at the same point, namely 3s. The inclination of the lines to the horizontal is interesting. It is obvious that the deeper the wind, the more inclined the cost line will be. If a horizontal line be drawn from the intersection of the cost lines with the line forming the left-hand margin of the diagram, the ordinates between the base

Mr. Clift. line and the horizontal line represent the fixed charges and labour. The ordinates between the horizontal line and the cost line represent the cost of coal per 100 tons wound. Obviously the latter cost increases with the depth of shaft. There is not time for me to go into the many subsidiary reasons which, in numerous cases, form powerful additional arguments for the introduction of electric winding. I have tried to make a comparison exactly as indicated by Mr. Mountain, and to make it as fairly as possible. If I have erred, I believe it is in choosing some figures for the steam winder which are more favourabe than would be attained in practice. It seems to me that the errors in Mr. Mountain's tables do not lead one to place great reliance on the remaining figures. But, apart from this, I believe that a careful study of the paper in conjunction with the data I have given will show conclusive evidence of the fallacy of Mr. Mountain's deductions. At the same time, we owe him many thanks for having raised the subject, giving us the opportunity for this discussion, and I shall be very glad if I have been able to add anything of interest to it.

TABLE A.

Test of Electric Winding Engine at Zollern No. II. Pit.

DISTRIBUTION OF POWER OVER THE SEPARATE SHIFTS.

	6—2 Morning Shift.	2—3 Winding Men.	3—10 Noon Shift.	10—6 Night Shift.
Total k.w.-hours delivered by generating plant	9076·33	715·82	7506·75	4770·79
Total steam consumption, lbs.	168,250	14,110	137,520	97,465
Steam consumption per k.w.-hour ...	18·536	19·71	18·318	20·43
K.W.-hours absorbed by winder	2192·07	83·96	1577·18	552·18
Effective H.P.-hours in shaft	1562·00	13·053	990·13	92·00
K.W.-hours per effective H.P.-hour in shaft	1·403	6·43	1·592	6·00
Steam consumption per effective H.P.-hour in shaft in lbs.	26·01	126·77	29·178	122·62

SUMMARY FOR THE TWENTY-FOUR HOURS.

Total k.w.-hours delivered by generating plant	22069·69
Total steam consumption	417345·00 lbs.
Total steam consumption per k.w.-hour	18·91 lbs.
Total k.w.-hours absorbed by winder	4405·39
Effective H.P.-hours in shaft	2657·183
K.W.-hours per effective H.P.-hour in shaft	1·657
Steam consumption per effective H.P.-hour in shaft ...	31·35 lbs.

		Coals in Tons per day of 8 Hours.	Depth of Shaft
Steam Winder	Case 3. Mr. Mountain's Figures	2,000	70
	do. do. do. (corrected)... ...	2,000	70
	do. do. do. Coal at 6s. per ton.	2,000	70
	do. do. do. do. 8s. do.	2,000	70
Electric Winder	Case 3. Mr. Mountain's Figures	2,000	70
	Siemens' Proposal	2,000	70
	do. do. Coal at 6s. per ton	2,000	70
	do. do. do. 8s. do.	2,000	70

The test was taken on November 25, 1904, and extended over twenty-four hours. The engine was winding at about half its full capacity from a depth of 200 yards. 2,423 tons of coal were wound in the two working shifts. At the changes of shifts 1,024 men were taken down and 1,007 men brought up; the weight of the men was averaged at 165 lbs. Mr. Clift.

The steam consumption was ascertained by weighing the water delivered to the boilers during the test.

TABLE B.

Name of Colliery.	Depth of Shaft. Yards.	Tons of Coal Wound per Day.	Effective H.P.-hours in the Shaft per Day.	Tons of Coal Burnt per Day.	Steam Consumption per Effective H.P.-hour in the Shaft.
Bolsover Colly. Co.	372	2,000	2,525	20·8	129
Denaby & Cadeby	763	3,360	8,700	46·0	83
Tredegar Coal Co.	272	600	554	6·25	177
Lancs. Colliery ...	775	755	1,986	14·45	114
Richard Evans ...	550	1,260	2,352	14·3	95
Silkstone Colliery	335	1,280	1,455	6·4	70
H. Rhodes ...	550	3,186	5,947	18·5	48
Hutton Colliery...	312	567	600	3·9	102
Do. ...	440	374	558	4·6	129
Atherton Colliery	376	581	741	2·75	58
Do. ...	489	581	964	2·75	45
Hickleton Main...	542	2,900	5,334	30·0	88
Sherwood ...	444	3,600	5,425	10·7	31
				Average ...	90

The evaporative capacity of the coal is taken at 7 lbs. of steam per lb. of coal throughout.

Mr. G. S. RAM: I should like to make one or two remarks with regard to Mr. Sparks's paper. At the last meeting Mr. Sparks drew special attention to the fact that he got out his scheme before the Home Office Mining Rules were issued. In one respect I think he has gone one better than the Mining Rules, and that is with regard to the method which he adopts for earthing all his metal work below ground—controller cases, switch covers, motor frames, and such like. There is often a difficulty in knowing how this can satisfactorily be done, but Mr. Sparks has got over it by running a special "earth" cable from the surface and along the roadways, branching to wherever it is required. The importance of having cases, casings, armourings, and so on earthed is very often overlooked. It is not realised by many people that the conditions in a mine are such that if a man gets a shock at all he is likely to get a very bad one, even although the pressure may be low. For example, in a case I had to investigate last year, a man Mr. Ram.

Mr. Ram. was killed by only 230 volts continuous current under circumstances which might occur in any mine. He was on his way out of the mine, and was passing along the main roadway. He had no clothes on his back, and the ground was wet. There were some tubs off the line, and he had to squeeze against the wall to get past them. In doing so he pressed his back against an armoured cable. It so happened that the armouring was alive, and he was killed outright. The usual excuse was made that the man must have had a weak heart, but the post-mortem examination showed that his heart was perfectly sound and that he was in other respects strong and healthy. Mr. Sparks does not say, however, how he earths the end of his "earth" cable. This again is an important matter on which people have very different ideas. I was at a colliery a fortnight ago where some substations were being put down, and earth plates were being put in while I was there. A hole had been dug 7 or 8 ft. deep, and three plates, each of ¼-in. galvanised iron, 3 ft. square, were put into it. The hole was to be filled up with a mixture of coke and earth. The total surface of the plates was therefore 54 sq. ft. In another case of a substation put down by a large power company, I thought I would investigate how they made their earth connection. I traced the earth wire to the outside of the building to where it went to ground. A man was sent to fetch a pick and a shovel to get some ground out. While he was gone I got hold of the wire and pulled it, and up came the earth plate. It measured exactly 7½ ins. square, the total surface being therefore less than a square foot. It was buried 6 ins. below the ground in perfectly dry earth, and was probably quite useless. That was also quite a modern substation. Coming to the question of the overhead transmission, I gather from Mr. Sparks's paper that where "cradles" are used they are intended to catch a broken wire and keep it off the ground so that nobody can touch it, but that where "catchers" are used they are intended to earth the wire if it breaks. It is not clear, however, from the illustration, how the catchers are earthed. Apparently they are merely connected to the barbed wire which is wound round the posts and ends in the ground. If that is all, I think it is probable that the earthing effect will be exceedingly small. In the case of one of the large power schemes, where they are using overhead transmission with steel poles, an earth wire is carried from pole to pole, connecting each pole, so that earth connections are made in many places. In regard to the generating station, there is one point, to which Mr. Sparks has given his attention, which is very important, and that is, that if any part of the apparatus in any panel goes wrong he is able to withdraw the panel from contact with any live conductor and execute any repairs in safety. That is very good so far as its goes, but I do not quite see from the drawings how, supposing anything goes wrong with the fixed contacts or main bus-bars, anything can be done there without shutting down. Possibly, however, they are capable of being divided up and made dead in sections. He carries out the same idea in the substations; that is to say, the conductors can only be got at when the pressure has been switched off. That is a very important point, which is sometimes

entirely overlooked. I was at a colliery substation recently where there were switchboards working at 2,000 volts and 6,000 volts, enclosed entirely in expanded metal. They were perfectly safe for ordinary working, but as soon as anything went wrong behind the screen, nothing whatever could be done without shutting the whole place down. Another important point had also been overlooked. Three separate 3-core cables of 2,000 volts were taken down the shaft and were provided with disconnecting links, so that if one cable failed, the other two could continue in use; but the advantage of the arrangement was in a great measure lost, as all three cables were connected through one switch, so that if the switch should fail the whole supply would break down. It is often astonishing to find how small points which are, in a way, of extreme importance under actual working conditions, are overlooked. Mr. Ram.

Mr. A. F. STEVENSON: I want to say one or two words in connection with Mr. Sparks's paper with regard to the use of high-tension core cables in a pit. In this case, where there is a skilled engineer to look after them, and to see that the earth connections remain on the switch-cases, and so forth, it is quite safe, but in the average colliery, where the man in charge of the plant is very often only an educated roadman, if the removing of an earth connection makes the plant work all right, he will remove it and let anybody take the risk. Mr. Stevenson.

After all, what is saved by doing it? A few hundred pounds of plant, and against that there is increased liability to break down (although, I suppose, the plant manufacturer will not admit that), greater risk to life, and further, the colliery managers themselves cannot be expected to handle 3,000 volts as they would 500. If anything goes wrong, they have to wait until the manufacturer can send someone down to put it right, and in the meantime thousands of pounds' worth of damage can be done. I have had myself many experiences of recklessness in pits, in spite of the Home Office Rules. For instance, I make a practice, when visiting a colliery, of inquiring as to the performance of the leakage indicator, and find that, in some cases, they have not yet got one; in others that, although the instrument is on the board for appearance, it is not connected up, and in others where the instrument is in working order, no notice is taken of its indications.

Even when a first-class firm is doing work in a colliery with a full specification for earthing and shielding, they may send down a man who is very good on generators and motors, but he may know nothing whatever about some of the other parts, and in that way neglect some very vital points in the connecting up of armouring and so on. I have had experience of that myself.

With regard to the cables used in the Powell Duffryn pits, as far as the underground work is concerned, I think many people who have done cable work in collieries will agree with me that paper cables are not very suitable, more especially when they are lead covered, as in many pits the water has a very bad effect on the lead covering; in fact, there are many pits where lead covering will not last twelve months.

Mr. Stevenson. I know of many cases where oil has run down the cable in the shaft until it has filled all spaces, and acquired such a "hydrostatic" head that the lead covering in one case was ripped open, and in another case the lid of a switchbox was broken.

Paper cables are much improved now, but that sort of thing may happen in a warm pit. Then, if a lead covered cable of that type is damaged, and there is water about, instead of having to repair, as with other cables, just that particular place, you may have to pull out many yards of it. With low-tension cables not covered with lead, if damage arises through a fall, in many cases the pump beyond the fall has gone on working, whereas with 3-core lead covered cables such a thing is impossible. I know of several large pits where they have gone so far as to dispense with 3-core cables in the shaft, using three single cables without any metallic covering on at all, and encased in wood, which enables them in a shaft of 600 yards to do without any joints. Joints, I think, are admitted to be a great source of trouble, especially in a shaft where there is much water and the means of attachment are very crude; and the use of light single unarmoured non-lead covered low-tension cables enables them to be dispensed with in both shaft and road in nearly every case.

Discussion at Meeting of April 5.

Mr. Patchell. Mr. W. H. Patchell: In connection with these papers the discussion seems to have centred more round Mr. Mountain's paper than around that of Mr. Sparks. With regard to the figures in Mr. Mountain's paper, I hope he will throw more light on them when he makes his reply, more particularly as regards Table I., which purports to show what steam winding engines are doing. We there have twelve examples, of which only two, Nos. 8 and 9, are marked as tests; but I find that in Nos. 1, 2, 8 and 11 the coal per wind multiplied by the number of winds per day equals the total tons of coal per day, so I presume that these are actual test figures, although it is only mentioned in two cases. In case No. 9 the total should be 374 and not 399, as set out in the column. No. 10 is hardly comparable with the others, because the winding is done from different levels. With regard to No. 12, Mr. Mountain gave a correction last week. I did not quite catch what it was; but as this paper was printed and circulated in March, I think a correction which the manager of the colliery published on the 25th of January in the *Iron and Coal Trades' Journal* should certainly have been incorporated. He writes in the *Journal* of that date that the total coal wound was 2,600 tons, not 3,600 tons, as stated by Mr. Mountain.

Mr. Mountain. Mr. Mountain: You will find those calculations are on 2,600 tons. It is a clerical error.

Mr. Patchell. Mr. Patchell: I am glad to hear that, but there is another! The cost per 100 tons is stated by the manager of the mine to be 3s. 1¼d., not 4s. 8½d.; and the latter figure, which Mr. Mountain puts down as the cost, the manager states is the cost including interest and deprecia-

Mr. Patchell.

tion. Further, on this particular test it is stated that there is a $17\frac{1}{2}$-hours' shift. But the ordinary English miner does not, as a rule, work for $17\frac{1}{2}$ hours on a shift. How the men came up in the meantime is not apparent—whether they came up by a man engine or another winding engine—but I presume that the shift is not continuous. In case No. 3 the arithmetic is again incorrect; the total should not be 550 to 600, but 1,324. In case No. 5 a similar mistake occurs; the total is not 1,260, but 1,080 tons. According to the figures put down by Mr. Mountain the engine is winding more than it could have wound. Passing to Table V., if the total lift is calculated from the data given as to the acceleration and retardation, I find that No. 1 would only travel 320 yards, not 500; No. 2 would only travel 346, and not 500; and No. 3 would only travel 400, and not the 700 stated by Mr. Mountain. I hope he will be able to reconcile these little discrepancies when he gives his reply; but in the meantime they discredit the other figures. We shall be very much indebted to any one who will give us true figures as to what either steam or electrical winding sets will do at the present moment, because all of us who are in any way interested in the business want to know. It is stated that electrical winding engines are out of the question for heavy work because they do not accelerate quickly enough. To know what an electrical motor can do in the way of accelerating we have only to look at what is being done now in railway work. The acceleration there is greater than ever was accomplished with the steam locomotive, and if rapid acceleration is wanted an electric motor will do it quite as well in a mine as it now can shake you off the seat of a railway carriage! But there is this important point: To get through the lift in a short time a steam winding engine has to give an enormous acceleration to get the mean speed necessary, and the driver frequently turns the steam against the engine or puts on the brake at the end of the wind. With an electric winder of the Ilgner type that energy, instead of being thrown away, is put back into the flywheel, so that the cage can be run at the higher speed nearer to the bank, and get a high average speed without getting the high acceleration. On the stand-by question, the figures relating to the winding during eight hours are interesting, but that is not where the money is lost. The difference comes in in the stand-by hours. Those of us who have plant which works a few hours a day and stands ready to work for the other 16 or 18 hours a day know well what that means. The winding engine has to be kept with steam on it, and the boilers have to be kept under steam ready to do full load instantaneously, so that the radiation losses are enormous. I do not think it would be too high to put the coal taken for stand-by work at 25 per cent. of the coal taken for useful work. Some interesting figures on this point were published by R. A. Henry in his paper in the *Revue Universelle des Mines* (Liége) in July, 1904. They are much too long to quote here, but much too valuable to pass by without referring to them. From some of the figures in his tables it will be found that 50 per cent. of the total steam used during the twenty-four hours was actually wasted—that is, it did no useful work.

Mr. Patchell.

With regard to Mr. Sparks's paper, Mr. Ram last week mentioned one point in connection with Fig. 11 upon which I would like a little more information. Could Mr. Sparks give us the scale? Part of the switchboard runs out on to a little wagon, which we saw when he showed the photographs, but one has no information as to what the scale is, although in some of the other drawings of the substation work the scale is given. I do not see how a man is to get safely over the wall after pulling out the switchboard and get at the ends of the feeder mains, or at what apparently are the bus-bars at the back, which, I take it, do not come out on the little wagons. To know really whether that sort of board is best for the purpose or not one would like to know a little more about it. On the question of the overhead lines, it strikes me that they are very close together for bare wires. I should like to know whether they have gone through a storm without much trouble, or what the effects have been, because these wires are hanging nearer together than I would have dared to put them. After a storm one finds out the weak spots, and one way of getting out of the difficulty might be by putting in another pole or two. With regard to the question of the tension to be adopted down a pit, there seems to be a feeling that high tension is bad under such circumstances. I do not believe that is so. I believe that high tension is treated with more respect; and when I had the honour of serving on the Home Office Committee I put that view very strongly before my brother committee-men. There is no doubt that low tension is dangerous, as we have had evidence lately. More men have been killed in the last few years by low tension than by high tension. Low tension is treated with less respect than high tension. If you give a man a high-tension plant to look after, he looks after it better, as he thinks it more dangerous, and that tends to the better up-keep of the insulation. But that is not the only point. The higher the tension, the less the current, and the less the danger when a burn-out occurs. I have had burn-outs at voltages running from 100, 200, 400, 500, 1,000 and 10,000 volts, and the smallest area of the burn-out was in connection with the 10,000 volts. I do not think that the low tension ought to have the preference shown to it with regard to safety that is shown to it in some quarters. The haulage data given by Mr. Sparks are just what are badly wanted. Many accounts have been published of haulage sets, and if anybody will take the trouble to check them they will find some are absolutely physical impossibilities. I have checked some, and find that the motor, even at treble its nominal rated load, would not move the "journey" or train of trucks. Electric haulage will not only save the coalowner money because it handles the part of the plant which Mr. Sparks admits has only 7½ per cent. load factor, and so is very bad, but it shows him at once, if he has instruments on his motor, where his road is bad. I saw an electric winding engine diagram lately in connection with a shaft which had rigid guides, and at one place the tightness of the guides and the undue work put on the machine were marked on every trip. I have known the same with haulage sets. If one has a steam engine or a horse, one does not recognise what he is

doing; a little more steam or a little more whip and it passes by; but with a motor it is seen at once by the ammeter that one part of the road is bad, and that money will be saved by attending to it. And not only that, but one does not wait for the road to be bad enough to let the trucks run off it, and so accidents are avoided that take time and money for repairs. In Mr. Sparks's final figures I am not sure whether his output is "at the rate of," or whether it is the actual output "for" twelve months. I should be very glad if he would tell us that. He sent me some figures lately for twelve months, but I gather from the paper that the plant has not been running for twelve months, and that the output is "at the rate of." Mr. Patchell.

Mr. SPARKS: We started last May: it is "at the rate of." Mr. Sparks.

Mr. PATCHELL: They were sent to me as the figures for twelve months' working, and I gave those figures a place in a table which I published at the end of the reply to the discussion on my paper read here lately. I put Mr. Sparks's figures in to compare with others which had been working for twelve months, and of course there is a vast difference between tests and the results of twelve months' working. Mr. Patchell.

Mr. A. J. BLOEMENDAL: I think that most of the remarks I desired to make on Mr. Mountain's paper have already been anticipated by the gentlemen who preceded me. There is one point, however, which has not been very fully discussed, and about which I should like to have heard something from those gentlemen who strongly advocated the use of electric winders, namely, some figures on the actual cost of working, and the cost of upkeep and repairs to electric winding engines. This is something that the colliery manager wants to know about more than anything else at the present moment—what are the costs of repairs, and what is the cost of upkeep of an electric winding plant. I think that there is no doubt that they will be considerably higher than the ordinary steam winder; for instance, in the Ilgner system, we have the additional cost of upkeep and repairs for four electric machines, apart from the steam engine which is common to both electric and steam winders. Mr. Bloemendal.

Referring to Mr. Sparks's paper, I should like to say one or two words. In the first place, I notice that the large haulage gears have only one motor. I have found it a useful practice with haulage gears employing over 150 or 200 H.P. to use two motors. This has many advantages, especially with a continuous-current system. One is that the use of two commutators allows of a simple speed regulation, and in one installation which I recently carried out, we, as a matter of fact, had two commutators on each one of the motors. From a miner's point of view the use of two motors is another advantage. The motors which have to run at a very low speed assume a very large diameter, which means that they require a good deal of head-room. With two motors the diameter, of course, is considerably reduced, and therefore less head-room is required, and I have found that the two motor gears are therefore, in many cases, to be preferred. A further advantage which I think can be claimed is in regard to the question of stand-by. In the case of a breakdown of a motor, with two motors on each gear, one motor can be used as a stand-by, the gear simply working with a smaller load

Mr. Bloemendal.

until the other motor is repaired and again put into working order. Therefore, apart from the question of speed regulation, I believe that these last two considerations, viz., the head-room and stand-by, make it desirable in every case, whether the motors are working on a continuous-current or 3-phase system, to use two motor gears. With regard to the fans described in Mr. Sparks's paper, I see that the motors are not arranged for speed regulation. I have found in many cases that the colliery manager requires a variation in speed with his fans in order to be able to vary the amount of fresh air brought into the mine according to his air-ways and the length of road. This will be especially the case if the mine is only just opened up. With continuous-current systems, speed regulation becomes comparatively easy, but with a 3-phase system, of course, as the only one which comes into consideration for large plants, the usual difficulty of speed regulation with 3-phase motors is encountered. In most cases it is necessary to insert resistances in the rotor, which, of course, means a greatly decreased efficiency. I have also tried, in one or two installations, to vary the number of poles of the motors, but this has not been very successful. If Mr. Sparks has any information he can give with regard to this subject, it would be very welcome to me. I also notice that Mr. Sparks has not given any figures with regard to the power, or the actual coal consumed for the different motors. I suppose the plant has not been long enough in operation for any of these particulars to be available. I may therefore be permitted to give some data which I collected about a week ago on a certain plant. It is interesting, as it offers an immediate comparison between the coal consumption for steam and electric power. In a mine recently equipped, a 150-k.w. continuous-current generator is driven by a Davy-Paxman engine, which has its own boiler adjoining. The generator supplied current for a number of pumps, haulage gears, and other machinery. One pump, however, has been left in the pit to be driven by steam, this steam pump, having its own boiler, which is situated at the pit bottom. The reason why this pump was not also converted for electric drive is because it was thought advisable to save the installation of a fan, as the boiler at the pit bottom is used for ventilation purposes. A thirty-six hour test during week ends was made; the first with the steam pump, which was delivering 15,000 gallons of water per hour. The coal consumption was measured, and it was found that per H.P.-hour of water delivered, 3·8 lbs. of coal were consumed. We then employed the generating plant for supplying current for a motor driving a 15,000-gallon electric pump only. The coal consumption was again measured, and it was found to be 3·1 lbs. per H.P.-hour of water delivered. These figures, I think, show greatly in favour of the electric power, especially as the generating plant was, of course, only working on a very small load in comparison with its total capacity. There is one more remark I should wish to make with regard to the haulage systems. Whereas in the United States of America, and also on the Continent, rope haulage has to a great extent been replaced by electric traction locomotives, very little progress has been made with this system in the United Kingdom. As, however, the colliery

Mr. Bloemendal.

manager is now very much alive to the question of reducing his working expenses, I think we shall soon find them introduced to a larger extent in this country also. The progress must naturally be slow, the same as it has been in those countries where electric locomotives are looked upon as the standard equipment of every well-managed colliery.

I have recently equipped some mines in this country with electric locomotives. As regards the cost of electric as compared with animal traction, the following figures may be of interest. In a mine where formerly horse traction was employed, the cost per ton in of coal hauled was 1·67d. After electric traction had been installed, this was brought down to about 0·9d., which, I think, speaks well of the advantages of electric traction. It must be stated that the interest on the cost of the plant and depreciation were taken into consideration in calculating the latter figure, whereas in the former the initial cost of the horses was not included.

Mr. Sparks.

Mr. C. P. SPARKS: I should like to make a few remarks on Mr. Mountain's paper. In view of the large saving made by applying electric driving for subsidiary purposes in collieries, as compared with main winding, in my opinion the latter should be deferred until the other drives have been converted, as, owing to the present heavy capital cost, it is difficult to show direct economy for electric over steam winding. On the other hand, I do not think the position is quite as hopeless as that shown in Mr. Mountain's paper. Examining the practice of various coalfields, we find that our Continental friends have gone in for electric winding on a large scale, although the reverse has been stated in this room. One gentleman referred to electric winders as "toys," but this opinion must have been based upon incorrect information. With the information before us, we may well ask why English colliery proprietors do not adopt electric winding. Some people might assume that it is due to apathy. Many of the colliery owners I have met are amongst the most enterprising traders of this country, and they are not debarred from adopting electrical winding by difficulty of finding the necessary capital, or through fear of going in for something that is a little experimental; but there are fundamental reasons why electric winding has not been introduced into this country. In my opinion, the reason electric winding has not been adopted here is this: If we take the cost as divided between capital and depreciation charges on the one hand, and the running costs on the other, we have increased capital and depreciation charges to meet on adopting electric winding. On the other hand, we have an advantage in lower fuel and running costs. Mr. Mountain, in Table II., hardly does justice to the electric driving, as I see the running costs put down for steam are lower than the estimated cost to be reached with electricity. I do not agree with him there. I am certain, owing to the steadier load and the lower stand-by losses, there is a very solid saving in fuel and running costs when working electrically, but at the moment the capital charges outweigh that advantage to such an extent that we have not been able to adopt electric winding here. The reasons for adopting it abroad are these: First, the hours of winding are nearly double. If we double

Mr. Sparks the hours of winding we naturally reduce the importance of the heavy capital charges and increase the importance of the running costs. The second reason is that fuel is dearer abroad than in this country; consequently the saving by adoption of electric winding is proportionately greater. Thirdly, we find that, in place of working with conical drums, the "Koepe" wheel is generally adopted to minimise the mass requiring acceleration. Lastly, we have the combination of electric winding, always in connection with the general use of electric power for all purposes. In his paper Mr. Mountain has debited the electric winder with the entire cost of a large generator and boilers, as if nothing else was supplied. This is an extreme condition; and I think we are all agreed that it is not a commercial possibility to adopt such a system of winding at the present time. I have had two opportunities during the last three years of employing electric winders where 750 to 1,000 H.P. were required. In one case there was a transmission of $2\frac{1}{2}$ miles; in the other, a transmission of 1 mile from the generating station. In the first case it was proposed to drive the winder direct from the generator, and in the second case on the Ilgner system. In both cases the saving of 40 per cent. to 50 per cent. in the running charges was more than counterbalanced by the extra interest and depreciation charges. In consequence, steam winding was adhered to, the guarantee given being comparable with the figures given by Mr. Mountain for modern steam winders, the coal consumption being $\frac{1}{2}$ per cent. of the coal wound. In my opinion, the whole question is summed up in the words, Can we reduce the capital cost of applying the electric winding?—and I think we can. The cheapest method is undoubtedly the direct drive. This is only practicable if the generating station has very large units and a large output, so that the peaks are relatively unimportant. At present the Powell Duffryn Works have haulage motors that each make sudden demands of 300 or 400 k.w., these demands being relatively unimportant when working with a unit of 1,500-k.w. capacity. That is to say, they do not influence the load factor sufficiently to affect the running costs. If a power company has units of 5,000/6,000 k.w., the varying load from an electric winder becomes relatively unimportant. As soon as the capital costs of the electric winder can be reduced, the running charges, in my opinion, will show an economy of 40 per cent. to 50 per cent., and will more than counterbalance the extra interest charges, which will allow electric winding to make progress in coal mines. If we take other mines, where fuel has to be bought, it will be found in nearly every case advantageous to apply electric winding at the present time.

One other point raised in Mr. Mountain's paper is in connection with the cost of energy. In a table which has been circulated this evening (see Appendix to Mr. Mountain's reply, p. 578) I see that in the case of the Grand Hornu Mine, with an output of 16,000 units per day, the cost for one working day, including interest and depreciation, is put down as 0·2d. per unit. I have not had time to check these figures, but in my opinion such a cost, including interest and depreciation, is too low. Again, with the output raised to 24,000 units

per day, it is put down at 0·16d. I think the figure I have given of the Powell Duffryn weekly costs (output averaging 15,000 units per day) of 0·36d., with the cost falling with the increased output to something under 0·3 of a penny, including 10 per cent. interest and depreciation, with coal at 4s. 2d. a ton, is more accurate than the figures given of one day's working cost at the Grand Hornu Mine. I think, on checking these figures, the 0·2d. would be raised to over 0·3d., and the 0·16d. would be raised to nearly ¼d.—that is to say, the cost per kilowatt-hour, allowing a proper amount for interest and depreciation, would be raised nearly 50 per cent. above the figure given in this table accompanying Mr. Mountain's paper. Mr. Sparks.

Mr. RUDOLF BRAUN (*communicated*): The power demand of winding engines varies between wide limits. During the decking period the winding motor does not consume any power, whereas during the accelerating period the load on the motor is equal to two or three times the average load calculated for the total time. The load curve will be Mr. Braun.

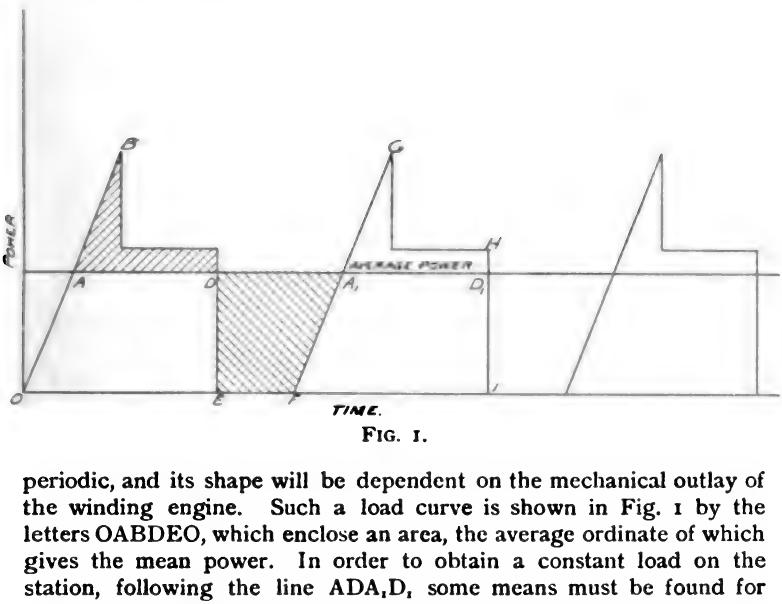

FIG. 1.

periodic, and its shape will be dependent on the mechanical outlay of the winding engine. Such a load curve is shown in Fig. 1 by the letters OABDEO, which enclose an area, the average ordinate of which gives the mean power. In order to obtain a constant load on the station, following the line ADA_1D_1 some means must be found for storing during the pause the energy represented by the area EDA_1F and for delivering it to the winding motor during the period of overload ABD. This result is obtained by using a heavy flywheel arranged so as to absorb energy during the interval DA_1 and to give back the same during the time A_1D_1. It will thus be possible to install a power station working continuously with 100 per cent. load factor, and designed for the average power demand, a condition under which electrical energy is generated with maximum possible efficiency. Different load-equalising systems have been invented, among which are the Westinghouse converter equaliser and the so-called Ilgner motor-generator systems.

Mr. Braun. The Westinghouse converter equaliser may be used in conjunction with either alternating or direct current motors.

The diagram, Fig. 2, shows the arrangement for use with alternating-current motors. This consists of a rotary converter (1) connected, through transformers (2), to the high-tension transmission line. The rotary converter on its direct-current side is connected to a direct-

EQUALISING SET.

Approximate

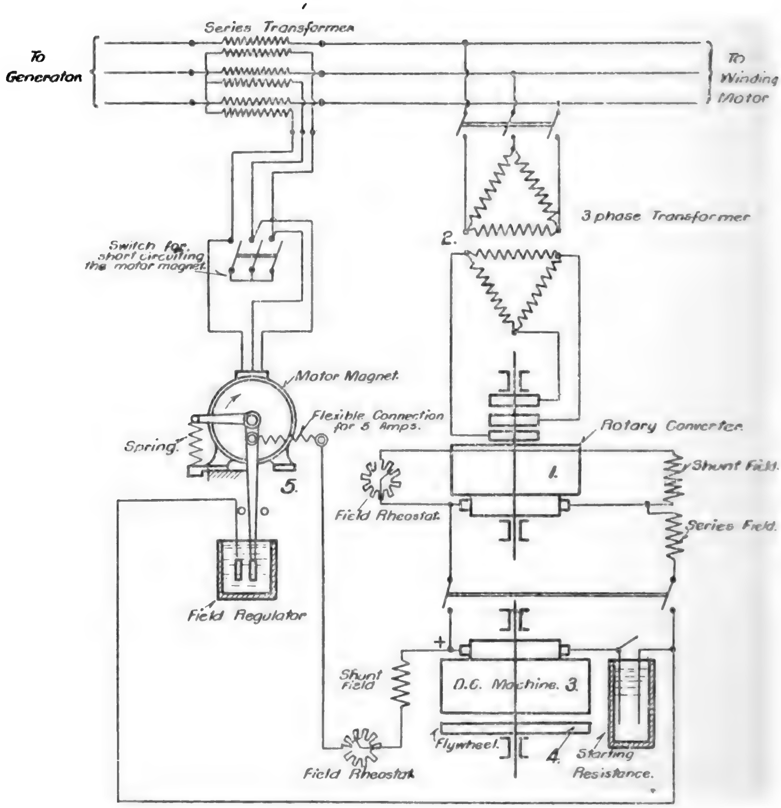

FIG. 2.

current machine (3), with flywheel (4), and is compounded in a special way so as to compensate automatically for the magnetising currents of the induction motors in the system. The voltage of the direct-current flywheel machine is controlled automatically, by a quick-acting regulating apparatus (5), from the high-tension transmission line through series transformers. This enables the converter equaliser to discharge energy

into the high-tension system whenever the load of the latter is greater than the constant station output, and to store up energy in the flywheel whenever the power demand in the high-tension supply system is less than the constant output of the station. When no load is on the high-tension system, the rotary converter is acting with 100 per cent. power factor, giving up to the flywheel the total constant station output until maximum speed is reached. The capacity of the flywheel is taken sufficiently large to take care of the overload and underload periods of the high-tension system. The flywheel machine is preferably built for high speeds, in order to obtain high electrical efficiency combined with light weight. The flywheel may have a maximum slip of 40 per cent. of its maximum speed ; in ordinary service 30 per cent. will be sufficient. The over-all efficiency of the converter equaliser—that is, the energy input divided by the energy output—is about 70 per cent., which is at least as good as that of a chemical accumulator, besides the advantage of a cheaper price for the output and the small cost for maintenance and repair. **Mr. Braun.**

In view of the fact that the converter equaliser is only handling *the overload* and *underload energy*, which represents but a small amount of the constant station energy delivered, the efficiency of the whole system will be considerably higher than without the equaliser. This is owing to the fact that without the load equaliser a larger station capacity to withstand the maximum load has to be provided, and is operated with a very small load factor. The average load factor of the winding engines in most cases is not higher than 15 to 20 per cent., and the same load factor is on the station without the load equaliser.

The converter equaliser in connection with alternating-current winding motors may be installed at any suitable place on the alternating-current system. It need not be situated near the winding motor.

The Westinghouse converter equaliser can also be used in connection with direct-current winding motors, and the diagram, Fig. 3, shows the general arrangement. The rotary converter (1) is connected to the alternating-current mains in the same way as in diagram Fig. 2. The direct-current side is connected to a direct-current machine (2), and this machine is fixed on the same shaft with a flywheel and a direct-current machine (3). This latter, being connected in series with the machine (2), acts as a voltage regulator in order to obtain a variation of voltage on the winding motor terminals (4) between minus maximum and plus maximum. The direct-current voltage of the machines (1), (2), (3) is one half of the maximum voltage of the winding motor (4), so that if the latter is built for 500 volts, the machines (1), (2), and (3) will have 250 volts each.

When the winding motor (4) has to be started, the voltage of the regulating machine (3) will be opposite to that of the machine (2). By decreasing gradually the voltage of (3) to zero, and increasing it in reverse direction, any desired tension between zero and maximum may be applied to the winding motor. In order to regenerate it is only necessary to decrease the voltage impressed on the winding motor.

Mr. Braun. The energy will always be taken from the alternating-current supply circuit with approximately 100 per cent. power factor; or leading current may be sent into the same by properly regulating the shunt field of the rotary converter. The voltage regulating machine (3) can sometimes be omitted and the winding motor (4) started by resistance. This will be applicable in all cases where the losses in the starting resistance are very small.

CONVERTER EQUALISER WITH D.C REGULATING MACHINE

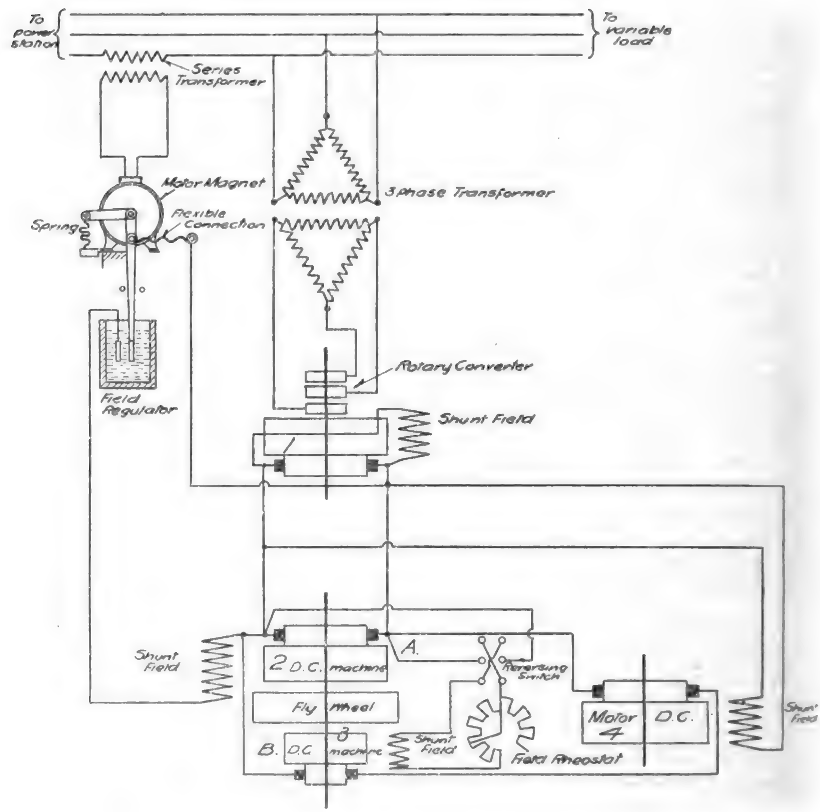

FIG. 3.

The converter equaliser as shown in diagram, Fig. 3, will also act so as to equalise at the same time the load variations on the alternating-current circuit produced by any other motors. It may be compounded in a suitable way in order to regulate the power factor of the whole alternating-current system. If equalising of the entire alternating-current load is not required, the automatic regulator will be connected into the direct-current side of the converter, and the motor magnet

operated by direct current. The converter equaliser for direct-current motors must be installed in the neighbourhood of the winding engine. Mr. Braun.

The direct-current winding motor will usually be shunt wound, particularly if electric regeneration is required. It may be series wound if used for large haulage gears.

The Ilgner system is an adaptation of the Ward-Leonard motor

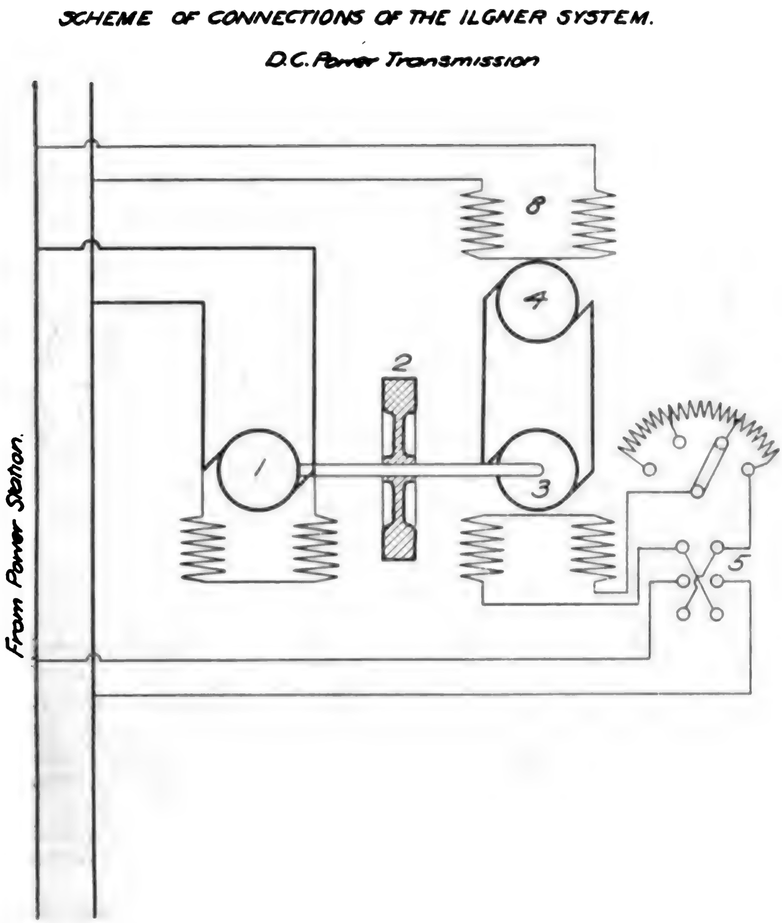

FIG. 4.

generator, with a heavy flywheel, to winding engines. Only direct-current winding motors can be used. The motor of the motor generator is either an induction motor with slip-rings (diagram, Fig. 4), or a direct-current shunt motor (diagram, Fig. 5). The generator is shunt wound and connected to the direct-current shunt-wound winding motor. The generator and the winding motor are separately excited,

Mr. Braun.

and by varying the excitation of the generator any voltage between minus maximum and plus maximum may be applied to the winding motor terminals. The operation is as follows :—

The motor (1) is first started and brought up to speed with the flywheel (2), dynamo (3), and the exciter (6) on the same shaft. The field circuit (7) of the exciter is then closed and current is supplied to the field winding (8) of the winding motor. By moving the controller (5), consisting of a reversible field rheostat, the field current of the

SCHEME OF CONNECTIONS OF THE ILGNER SYSTEM.
A.C. POWER TRANSMISSION.

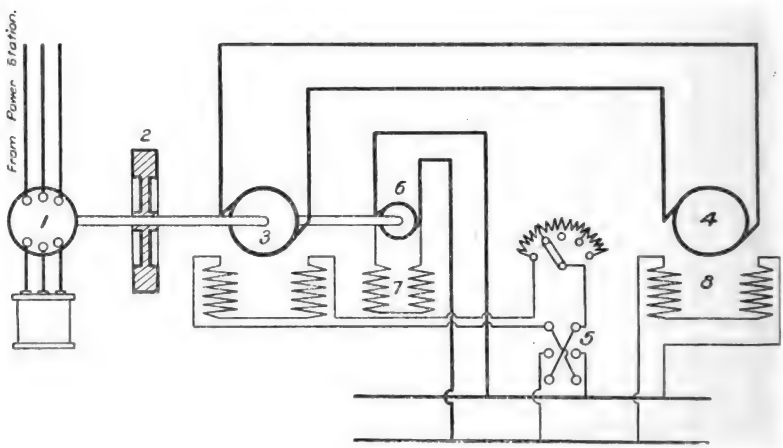

FIG. 5.

generator, and consequently the voltage at its terminals, can be varied to any desired degree. In order to let the flywheel discharge a part of its kinetic energy, the motor coupled with it must be allowed to slip. This is obtained by inserting resistance in the secondary of the induction motor, or by regulating the field excitation of the direct-current shunt-wound motor. The regulation is arranged to work automatically and keep the input of the motor constant.

With an induction motor the speed variation can for economical reasons be not higher than 10 per cent. of the maximum speed ; with a direct-current motor it may be as great as 30 per cent.

Mr. Whitmore.

Mr. L. F. WHITMORE (*communicated*) : As a contributor, more or less, to Mr. Mountain's paper in connection with the figures and estimates given by Messrs. Fraser & Chalmers, I have very little to add that is not made clear in this paper. On behalf of the author I may safely say that steam engine builders and electric winding engine makers have every reason to appreciate the trouble that Mr. Mountain has taken over this subject. There is, without doubt, a very large field for both classes of manufacture, and if, as his paper points out, steam winding has the advantage over electric winding in deep

shafts, and especially in single pits, there is undoubtedly a large call for electric machinery in that part of colliery plant where it has for some time superseded, and has the advantage over, steam plants. As some doubt obviously still exists as to the relative advantages of electric plants *versus* steam in winding, this paper offers an opportunity, if not of arriving at any decided conclusion, at least of obtaining the opinion of experts in both steam and electric winding, coupled with the practical experience of those who have to deal with existing plants, and consequently a more enlightened view should be obtained of the whole matter in the future. In a great many instances electric winding has been quoted and argued favourably over steam winding when comparing the cost with that found with steam engines that are obsolete in design. To find an extravagant engine of this class is easy, and would show up steam winding as a failure compared with recent electrical propositions. There is a different complexion on the matter, as shown by Mr. Mountain's paper, as soon as it comes to comparing electric winding with steam plants of recent build, and it is quite safe to say that they are not in the least bit exaggerated from the steam winding point of view. Table I. in Mr. Mountain's paper is decidedly interesting, but it is very hard to make accurate comparisons, as the winding circumstances vary so much, also the load, and the time allowed for winding—all of which have a great deal to do with steam consumption. Mr. Whitmore.

The Sherwood winding plant, quoted by Mr. Mountain as a modern plant, is one in which the coal consumption is greatly reduced when compared with the average run of collieries; the average coal consumption for the whole plant being less than 2 per cent. of the output of the colliery. This is a very satisfactory figure, and, although to a large extent due to high-class winding plant, it is also somewhat accounted for by the minimum horse-power required in other parts of the plant, such as for fan, electric haulage, etc., seeing that the colliery is quite a new one. The winding engine referred to, which is a high-pressure non-condensing engine, with cylinders 26 ins. by 54 ins., drum 11 ft. diam., is not installed for the main work of winding coal, but up to about a month ago it was practically drawing the output of the colliery. Since then their main coal-winding engine has taken up the work, leaving the high-pressure engine for winding men and such auxiliary duties. For this reason the best economy was not a point considered when these engines were put in, and on the load that they were winding—particulars of which are given in Mr. Mountain's paper, Table I.—the engine was decidedly overloaded, as can be seen from the indicator diagrams taken during the test. Furthermore, the feed-water heater, which is usually in operation, was not used on the two boilers set apart for this test, so that under normal conditions the coal burnt would be less than that stated. Now, comparing this with the best results given in Table I., viz., H. Rhodes, Rotherham, the output is only 2,600 tons in 17½ hours, as against 3,186 in 11 hours. It can be readily seen that the Sherwood engine could deliver practically the same output as Rotherham in 11 hours, provided that the time for

Mr. Whitmore. banking was the same as Rotherham, viz., 7–10 secs. instead of 43 secs. Under these altered conditions the total cost per 100 tons wound would be considerably reduced from the wages point of view alone, as Table I. shows allowance for two shifts of men, as against one for Rotherham. Therefore, with the wages the same as for Rotherham, which is a liberal figure, and with 720 winds per day, of which 680 would be for coal and 40 for men, the total output per day would be 2,920 tons. The percentage of coal used to coal wound would remain about the same, viz., 0·4, as I have allowed for a greater number of winds for men, and as an off-set to this, continuous running would somewhat reduce the percentage. The total wages per 100 tons wound put at 8d., cost of coal per 100 tons wound 1s. 5½d.—the total cost per 100 tons wound, with interest and depreciation, would come out to about 3s. 9½d., lower than any other example in Table I. I have pointed out that the Sherwood engine was not installed as being one of the most economical type; but the design of modern engines, even of this type, is such that the running costs of a colliery, mainly due to same, show so advantageously in this Table I.

The advantage of compound winding over duplex has already been proved beyond doubt for pits, say, 400 yards or more in depth, and to a still greater extent when they are provided with condensing plant. Recent results have shown that it is quite reasonable to expect a saving of 25 per cent. over the results obtained by the Sherwood duplex engine if a compound condensing winding engine is installed to do the same work. As a matter of fact, the permanent winding engine at Sherwood, which is now dealing with all the coal winding, is a high-class cross compound engine, intended to be run condensing later on; and although there has not at present been any test made to ascertain the exact differences of consumption between the two engines, there is sufficient evidence to show that there is a considerable saving of coal since the compound engine has been started up. It is intended to make a test of this engine later on, so as to arrive at this definitely.

These remarks show definitely that great advances have been made in steam winding plants, and unless electrical comparisons are made with plants of recent date it is impossible to arrive at any close approximation of the relative values of same. Messrs. Markham's figures on Table III. are equally interesting in that they show how closely their steam consumption agrees with that of Messrs. Fraser & Chalmers on Tables II. and IV. Now the engines referred to in Tables II. and IV. are cross compound, not coupled high-pressure, as mentioned in the heading. Compared with Table III., which is for a coupled high-pressure non-condensing engine, the coal burnt per day in case No. 3 is 11¾ tons. In Table IV., for a cross compound non-condensing engine, the coal burnt per day is 13 tons, representing a saving of 1¼ tons in favour of No. 3. The figures given in Table IV. by Messrs. Fraser & Chalmers were based on actual results, and it will be interesting to know if Messrs. Markham's figures given in case No. 3 are also obtained from actual results, and, if so, under what circumstances the engine was running. It must be understood that Messrs. Markham

Mr. Whitmore.

and Messrs. Fraser & Chalmers were given certain conditions in which to arrange three different cases of winding propositions. The conditions given, however, left the matter very open. It is therefore quite feasible that, with the many and varied conditions of winding, the results may not be altogether compatible until the exact conditions are known under which the results are obtained; and I would suggest that had Messrs. Markham proposed compound condensing winding engines instead of high-pressure engines, as they have done in Table III., they would have shown a better result than they have obtained.

It has frequently been suggested that the modern type of compound winding engine is a complicated machine, and requires the attention of skilled drivers, which would add to the wages. This, however, is entirely wrong, as in every case under my notice where compound winding engines have been started up, the drivers who handled the old engines have been put on to handle the new ones, and in a very few days they have become thoroughly accustomed to the new machine which, if properly designed, is made so that the man cannot tell the difference between driving this and driving a duplex engine. There is not the slightest difficulty in running slowly, starting, or stopping at any point, nor should there be any jerk on the rope. With common-sense attention there is no reason why such a plant should not be maintained in good running condition for years, approaching in life some present winding plants, and neither should the wear and tear be any greater.

There is another point in regard to winding plants which I mentioned briefly at the Manchester meeting, and that is the introduction of the Rateau steam regenerating plant and Rateau turbine, coupled direct to a generator and driven by exhaust steam from the winding engine. This is a system which is now becoming well known, and is likely to increase the efficiency of existing colliery plants and to reduce the steam consumption of colliery plants even of the highest class. Briefly, the system is one in which the exhaust steam from the winding engine is delivered into a large receiver or receivers filled with water, or, in some cases, scrap iron, the effect of which is that there are large volumes of steam coming in at about atmospheric pressure, giving out a great deal of this heat to the iron or water, the remainder going, by steady flow, to a Rateau steam turbine connected to the receiver, which, in turn, exhausts to condenser. When the winding engine is shut down, the water or iron in the receiver gives out its heat in the form of steam immediately the pressure begins to drop. The flow of steam to the turbine is therefore sufficiently even to admit of continuous running, even supposing the winding engine is shut down for a few minutes, and, of course, where occasion requires, a pipe delivering direct from the boilers, with a reducing valve, can be fitted. There are instances where there has been more horse-power obtained from the turbine plant than the winding engine (supplying it with steam) developed itself. There is a ready use for the electricity generated by the turbine plant in all collieries, and, to say the least of it, this system is a move in favour of the installation

Mr. Whitmore.

of steam winding plant, as the combination is so simple and the chances of breakdowns are, in consequence, reduced. It may be argued that under these circumstances it is not necessary to install high-class winding engines when the steam is required for a secondary plant, but on looking closely into the matter, the advantages of high-class winding engines at a reduced steam consumption (coupled with a turbo-generator) will be found more than sufficient in steam capacity for the demand of electricity required on the colliery, and will be well worth the extra cost of the highest class non-condensing winding plant, especially when it is considered that the steam consumption of the winding plant will probably be 35 lbs. per I.H.P., as against probably 55 lbs. in an ordinary horse-power engine, which surplus will be blown to the atmosphere. Where there is a demand for a larger supply of electric power than it is possible to obtain from the steam exhaust from a high-class compound winding engine, it is advisable in such a case to add a high-pressure set of wheels coupled to the same shaft as the low-pressure turbine, or, if preferred, an independent turbine exhausting into the low-pressure turbine, the horse-power turbine receiving a constant supply from the boilers, for the reason that steam can be used so much more economically in a high-pressure turbine than it can be in a low-pressure turbine. A feature which cannot be ignored in steam winding plants is the fact of having all the winding plant combined in one machine. This feature alone leaves the steam winding plant far ahead of any electrical propositions that have, so far, been introduced.

There are a few points in Mr. Hooghwinkel's paper which I cannot agree with. He refers to the average steam consumption taken for fifty collieries as being 100 lbs. of steam per useful horse-power-hour on the rope in average working. As I have already pointed out, to make comparisons with existing obsolete winding plants is unfair, and by so doing an altogether erroneous conclusion will be arrived at. Modern high-class engines are being installed every day, and the relative reduced steam economy is bound to result. He mentions 25 lbs. of steam per useful horse-power-hour drawing 3,000 tons from 770 yards, and suggests 40 lbs. cannot be obtained by steam winding plants under ordinary running conditions. In the first place, was the 25 lbs. obtained under ordinary running conditions? In the second place, I would say that there will be no difficulty whatever in obtaining a steam consumption of 30 lbs. per shaft horse-power per hour from such a depth and with such a tonnage by steam winding plants. An exhaustive test has recently been made in South Africa on a compound condensing winding engine winding from a vertical shaft 2,290 ft. deep, in which a steam consumption per shaft horse-power-hour of 25·55 lbs. has been obtained. These results will probably be published shortly. Mr. Hooghwinkel gives an example of a steam winding plant, and takes for same the Hulton Colliery, which, it will be seen at a glance, is the worst of all those on Table I. The modern development of mining plants in all directions should certainly suggest to Mr. Hooghwinkel that steam winding plants of the present day may reasonably be

expected to improve, and be at least as good as the best of the old installations. He is apparently also unaware that it is becoming a general practice to fit all winding engines with safety appliances, which make it practically impossible for a driver to overwind and cause other accidents. Mr. Whitmore.

I know of no reason for having separate boilers for steam winding plants, as suggested by Mr. Hooghwinkel. Referring to his table, I am able to state the actual results obtained by the Sherwood Colliery test, which shows 43 lbs. of steam per useful horse-power-hour instead of 50 lbs., as shown by the table. As I have already stated, a saving of 25 per cent. may be expected; if a high-class compound engine is installed to do the same work as this engine was doing, it would reduce this consumption to 33 lbs. of steam per useful horse-power-hour. Then, with regard to the other winding instances in Mr. Hooghwinkel's table, I shall be glad to know how he arrived at the other steam consumptions, as they appear to be very high and no details were given in Mr. Mountain's paper, from which the figures were taken. It is evident that it will be necessary to look elsewhere for the advantage of electric winding plants over steam winding plants than in connection with the difference of steam consumption between the two. In conclusion, I would say that we have no reason to suppose that steam winding has arrived at its maximum efficiency.

Mr. H. E. MITTON (*communicated*): I have read with much interest Mr. W. C. Mountain's paper on electric winding, and I consider that he has touched upon a subject of great importance to mining engineers. In Table I. it is difficult to arrive at a true comparison of cost per 100 tons raised, owing to the varying prices charged for fuel consumed and the different duties performed by the various engines, some of which appear to be designed to perform considerably more work than what they are actually doing. Mr. Mitton.

At present there is no large winding plant that I know of at work in this country, and until some such plant has been erected, I am inclined to agree with Mr. Mountain's views, that owing to the heavy first cost of an electrical installation the charge for interest and depreciation would be so heavy that it would not compare favourably with a well-designed steam plant for winding purposes. I am inclined to think that at present the only way an electric winding plant could be utilised to compare favourably with a steam plant would be by obtaining the power from some central power distribution company, where it might be possible to obtain it at a reasonably low figure.

Mr. ALFRED J. TONGE (*communicated*): We are very much indebted to Mr. Mountain for the amount of trouble he has been put to, and for the way in which he has marshalled the various facts together in regard to colliery winding. In a paper of such scope it is almost impossible to elaborate and explain the conditions under which each of the engines is working, and it will be extremely difficult to reduce them to one common basis. Mr. Mountain has made an attempt to do so by grouping together the whole cost of engines and boilers, including interest and depreciation, wages, and coal consumption, and to propor- Mr. Tonge

Mr. Tonge. tion this to the amount per 100 tons wound. This method may be very reliable where the object is to compare the cost of winding by steam and electricity respectively upon the same shaft and under the same conditions, as Mr. Mountain has done in the tables in his paper, but for general purposes I think Table I. would have been considerably more valuable if Mr. Mountain had added another column showing the amount of cost per 100 tons per foot lifted, or an additional column showing the amount of steam consumed per hour per horse-power in coal wound. Of course, Mr. Mountain has expressly stated in his paper that he did not wish to follow on these lines, but before any colliery engineer can estimate the advantage which he is likely to gain by substituting electricity for steam winding it would seem absolutely necessary to have these figures made clear. There are so many variations in the work attaching to labour and to the qualities of coal consumed at the boilers that this definite basis for comparison is required. Taking the question of value of coal consumed at the boilers: In Mr. Mountain's table the lowest value is shown as 1s. 6d. per ton, whereas the highest is placed at 6s. 3d. per ton. It would be a difficult matter for one to say whether this is the true proportion, the probability being that if the calorific value of the two coals were taken they would come much nearer together; consequently the table is affected considerably by local selling conditions. Mr. Mountain has pointed out that the engines at the Hulton Collieries are not doing the amount of work they are capable of doing, and this is more apparent from the outputs shown than was really the case at the time of the test. The real object of the test was to obtain the amount of steam consumed to the horse-power in coal raised, and a definite number of hours was taken. The daily winding of coal exceeded the amount wound during the test, so that the amount put down for wages of engineers and boilermen, depreciation, and interest are in practice correspondingly reduced.

In a paper read by me before the Midland Institute of Mining, Civil, and Mechanical Engineers in January, 1905, an attempt was made to expand the figures taken during winding into the whole period of twenty-four hours, the week, and the year. By doing so it was possible to arrive at leakage and condensation losses, and to find the influence of the non-working hours of the week or year upon the whole amount of steam used throughout the year. In the consideration of electric winding and steam winding it would seem necessary that these proportions should be taken into full account. On the whole, however, the figures set forth in Mr. Mountain's paper are probably as accurate as it is possible to get, when the information has to be gathered from so many different sources, and they will be extremely useful to the mining world, and I wish again to thank him personally for his paper.

Mr. Brown. Mr. C. S. Vesey Brown (*communicated*): Mr. Sparks is to be congratulated in being able to present such a record of colliery electrical equipment. It will be observed that all the most favourable conditions possible to the cheap equipment are available. The area is compact, three miles being the utmost limit of transmission required;

overhead wires can be used everywhere, and 3,300 volts enables the energy to be used direct on two-thirds of the motors. I question if such a favourable result in capital and revenue costs could be shown if higher pressures, underground cables, and transformers had been used. The figure of 0·365d. given as the result of the present experience, with the possible reduction to 0·3d. per unit, is one which is likely to lead to considerable agitation in the minds of many colliery managers, and especially so where "power" is being bought at rates varying from 0·45d. to 0·55d. per unit, and even higher. I hold no brief for the "power companies," but I think that the results should have been more clearly stated, for the following reasons: Where "power" is purchased from a statutory power company there are the following items to be added to Mr. Sparks's figures:— Mr. Brown.

1. Extra cost of transformation, as most power companies supply at 5,500 or 11,000 volts.

2. Extra cost of underground cables laid along public roads at a considerable cost for reinstatement as regards the roadways.

3. The fact that primarily the colliery companies, as a rule, require the power for some plant with very low load factor.

If the extra cost of 1 and 2 are added to Mr. Sparks's figures, and allowance is made for the third item, the cost per unit will be nearly ½d. instead of 0·365d.

I agree that continuous use of "power" for pumping and ventilation is worth considerably less than ½d. to both buyer and seller, but so far the power companies have been unable either to see that their best consumers are "continuous users," or that the cost of financing the company has been so high that they are not able to reach low enough prices to tempt "continuous users" to take "power." I think Mr. Sparks should qualify his costs under such favourable conditions. It cannot do harm to possible installations of a like character elsewhere, and it will help to explain the discrepancy between his result of 0·365d. and the prices charged by power companies for current where the conditions of supply are not so favourably arranged for as in the Aberdare installations.

Mr. Mountain's paper has been attacked by almost every speaker so far. His figures as to cost appear to be the *bête noir* of all those who are interested in the application of electricity to winding engines for collieries. I must say that the previous speakers have dwelt too much on the question of cost. There are other considerations which should be taken into account. The British colliery-owner is not so well protected as the Continental coalowner; his market for coal is world-wide, and is in competition in many instances with coal mined under artificial conditions as regards duty and taxation. The British coalowner prefers to employ his capital in the direct application of "coal getting" appliances, and not in elaborating the plant for removing the coal from the pit. I am quite certain that the large majority of colliery-owners in this country would prefer to spend the difference between electrical and steam winding gear on the mines themselves, as, for instance, in mechanical coal-cutters, underground haulage, and

Mr. Brown. pumping. To suggest to them that a fraction of a shilling per 100 tons can be saved per annum on winding is no great argument for the adoption of electricity. And after all, what is the difference in favour of electricity on a colliery where the output is half a million tons per annum? According to Mr. Clift, on a 700-yard shaft with 2,000 tons per day, the difference in cost is 2½d. per 100 tons, or £520 per annum. As against this, there is the uncertainty of the continuity of supply. The winding engine of the colliery is the one appliance which may be called upon at any moment to rescue several hundred men in a very short time. What would be the effect if these men were dependent on the use of a machine which in its turn is dependent absolutely on the perfect insulation of cables, transformers, switchboards, and generators? A steam-pipe may leak at any of its joints and still be "usable," but a cable may not leak anywhere without the gravest risk that the current will be cut off. A drop of 50 per cent. in the steam pressure of the boilers supplying the winding engine is not such a serious matter as to prevent the running of the engine, but a drop of 50 per cent. in the E.M.F. supplied to a motor would seriously impair its running satisfactorily.

Members of the Institution who advocate so strongly the indiscriminate use of electricity for winding are apt to lose sight of the fact that electricity *may* be able to do everything, but is it advisable that it should be pressed into the service of man everywhere? On the whole, I prefer to agree with Mr. Mountain that, until a very much larger saving can be shown between the two systems, and until the electrical plant is as reliable, steam winding still holds the field.

Mr. Sayers. Mr. H. M. SAYERS (*communicated*): Where the power has to be generated on the spot, the main advantage of electrical winding over steam winding appears to be the possibility of regenerating some of the acceleration work, and giving the driving engine a more uniform load. Whether this is worth the additional capital and maintenance charges or not cannot be settled as a general proposition, but it is evident that the handicap is heavily against electrical winding so far as capital charges go. Mechanically speaking, the present practice in main shaft winding appears to be at fault, a survival of the days of manual and animal winding. The load factor of the whole of the plant employed, including the shaft, is so low that capital charges form an unduly great proportion of the cost of working, whatever the motive power. This means an absolute waste of capital, as compared with that theoretically necessary. As an example Mr. Mountain's first case in Table V. will serve, winding 1,000 tons in ten hours from a shaft of 500 yards depth. This is an electrical wind, and the regenerative action is evidently utilised to considerable advantage, since the overall efficiency, coal lifted to engine power, is 39 per cent. The useful horse-power (coal lifted) is 212, taken as uniform over the whole time, but the maximum power needed during acceleration is 1,300, and the steady running horse-power 540. With steam winding the figures are, no doubt, worse.

The moral seems to be that a different method of winding affords the only remedy. The ideal method would be a continuous operation,

in fact, a vertical conveyor, and it does not appear that the design of such apparatus presents serious difficulties. Still keeping to the example above quoted, a conveyor speed of 5 ft. per second would give as great a delivery of coal in a given time, if one tub were attached at every 75 ft. of length. This speed contrasts with the maximum of 38 ft. per second required with the cage method, and suggests that the durability of the actual winding gear would be better than obtains at present. Assuming that it is necessary to lift the coal in tubs, as at present, there is no difficulty in devising automatic means of exchanging the full and empty tubs at the head and foot of the pit, and it would be perfectly safe and practicable to wind men in a similar way. It appears probable that the diameter and cost of shafts for equal winding capacity might be considerably reduced by the adoption of such means. Mr. Sayers.

Mr. A. DU PASQUIER (*communicated*): On reading Mr. Sparks's paper carefully, one finds very little to criticise, and has to confine one's self to seeking for additional information. To start with, I should like Mr. Sparks to tell us what reasons led him to adopt a periodicity of 50. It can hardly have been on account of the lighting supply, as this apparently amounts in all to 170 k.w., of which a considerable proportion must be underground, where 25 periods would have been perfectly satisfactory; and, if not deemed steady enough for the surface work, it would appear as if this could have been well met by small motor generators, or by motor driving existing generators, of which there apparently existed a good number; and there is no doubt that with the lower periodicity it would have been easier to get the lower motor speeds Mr. Sparks considered advisable. A 300-H.P. 48-pole motor at 121 r.p.m. is a very much more costly machine than a 25-period motor at the same speed, and would not have so good a performance. Mr. du Pasquier.

I would also like to ask Mr. Sparks whether he considered the question of turbo-generators for his power station, as although the 750-k.w. sets are rather on the small size for turbines, and there would probably have been little or no advantage in the steam consumptions, there might have been considerable advantages in the way of foundations, having regard to the site chosen.

Coming to the transmission line, it would appear that the Powell Duffryn line apparently consists of three wires, each of 0·08 sq. in. sectional area, which on the basis given would only supply about 500 H.P. of motors installed, and it looks as though there is some mistake in the figures given, unless the load factor of these motors is exceptionally low, or, perhaps, I should say, the diversity factor exceptionally high, or there are some other good reasons not stated. The shaft cables, on the other hand, appear large in some instances for the present work, but presumably it is the intention to provide for extensions, possibly having in contemplation the installing of some of the surface haulages underground in the future. Perhaps Mr. Sparks could give us some figures as to the economy to be effected by putting these engines underground, in respect to the upkeep of the ropes in the shaft and the increased friction.

Mr. du Pasquier.

With regard to the question of motor speeds and gear reduction, one would like to know why Mr. Sparks fixed on the speeds of 121 r.p.m. and 290 r.p.m. for the 300-H.P. and 150-H.P. haulage motors. In the case of the 150-H.P. gears, the drum shafts apparently make about 30 r.p.m., and unless one reduction can be cut out entirely, there does not seem much to gain by adopting speeds below, say, 480 r.p.m., which would be a standard speed, and permit of two reductions of 4 : 1 each, which is usually considered good practice. The motors would probably be cheaper, or, if built on the same frame, the performance would be better. In this connection the power factors of these variable speed motors appear rather lower than would be expected. The weights of the motors given are very interesting. I presume the figures given for the air-gap are iron to iron, and not total gap, but, judging roughly by the weights, one would almost expect them to be total gap. The figure on page 489, dealing with the rotor voltage and current at starting and full load, is not quite clear to me, and I should be glad if Mr. Sparks would further explain this, as it looks interesting.

Coming to Table V. in Mr. Sparks's paper, there appear to be some discrepancies here. A motor speed of 290 r.p.m., with the gear reductions stated, would give a drum shaft speed of 23·2 r.p.m., and assuming a mean drum diameter of 5 ft. 6 ins., which would be excessive unless there is considerably more rope on the drum than is required for the haul, this would give a rope speed of approximately 4½ miles per hour, instead of 5½ as stated. The point may not seem important, but it is interesting in checking up the current consumptions in Fig. 9. Referring to this last curve, it looks as though the last "rise" is due to excessive braking of the tail rope, and as though the driver could have avoided this by notching down on his controller a bit sooner. The same discrepancy in drum shaft speed and ratio of reduction appears again on page 495. The load curves given on page 496 are most interesting, and full of valuable information to any one who has to do with schemes of this nature, and I think our best thanks are due to Mr. Sparks for publishing such valuable information so unreservedly, as precise figures of the load variation on such a supply are very difficult to obtain at present. I trust Mr. Sparks will find time in his reply to deal with the various points I have raised, and I wish heartily to congratulate him on the very successful plant he has engineered, and his very interesting paper.

Mr. Anderson.

Mr. A. C. ANDERSON (*communicated*): I have only been able, to my regret, to read Mr. Sparks's most interesting paper very hurriedly, but I am rather struck by the fact that, as far as I can see, no motors are used for coal-cutting in the Powell Duffryn installation. In such a very up-to-date plant this seems peculiar, but it may be that the floors and roofs are bad and of varying level. If a fall of roof has occurred it would be very interesting to know how the leather-thong arrangement of suspending the cable therefrom answers in protecting the latter. I note that in some cases—for fan, screen, and aerial ropeway motors—liquid

starters are used, and that in connection with haulage, winding, and pump machines, presumably others, possibly metallic, are employed. Have the liquid starters proved unsuitable for the heavier class of work? The rival claims of these two types of starters for use in mines are of much interest, and any account of the author's experience in this direction would be very valuable. I take it from the paper that the A.C. lighting load amounts to 125 k.w. This bears a very small proportion to the whole, and as I suppose the frequency of 50 was decided upon because of the lighting, it is most unfortunate that lamps cannot yet apparently be made to operate successfully on a circuit of 25 cycles, for such a periodicity would probably have meant motors both cheaper and more mechanical, as well as of better power factor. I think Mr. Sparks is to be congratulated on the careful way in which the installation has been carried out. As an instance, the special arrangements for earthing motor frames, etc., may be cited. It is by such thorough thoughtfulness in design that the claims of electricity for use in mines are advanced. Mr. Anderson.

Mr. A. S. Clift (*communicated*): With regard to the revised data given by Mr. Mountain at the previous meeting:— Mr. Clift.

Mr. Mountain gave 800 to 1,000 k.w. as the steady power which would have to be supplied by the generator. I do not agree with this, my figure being 680 k.w., and on the basis of the latter I think that the figure given in my table for the cost of generating plant will be found ample. It is possible that Mr. Mountain's over-estimate of the power required accounts also for the excessive boiler capacity which he says would be required.

The figures given by me for steady running horse-power are not intended to represent the actual horse-power in the shaft, but the horse-power which must be delivered to the motor driving the flywheel set. They, therefore, include all losses from the terminals of this motor to the cage.

I fail to see how the weight of the flywheel required can be deduced from Continental or any other practice. It is a matter for calculation in each individual case. One reason for the use of heavier flywheels on the Continent is that usually the interval between winds is very much longer there than here, and the length of this interval can be easily shown to have a direct effect upon the weight of the flywheel. The speed given by Mr. Mountain is lower than should be chosen for a well designed plant to operate under the conditions met with in this country.

Mr. G. Stjernberg (*communicated*): Mr. Mountain's paper is intended as a comparison between electric winding and steam winding, but such a comparison clearly does not give correct results as far as economy is concerned, if it is confined only to the period of full work. No efficient steam engine working at its full capacity, fed from boilers erected close to the engine, can be economically replaced with electric motor and corresponding steam generating plant if we consider it apart from other demands for power. There are no tables needed to prove that. Winders, however, belong to a Mr. Stjernberg.

Mr. Stjernberg. class of machinery which generally works at full output only something like 2,000 hours a year, and during the other 6,760 hours they remain standing under steam. There is a considerable constant loss owing to condensing in pipes, cylinders, etc.; further, there is a constant boiler loss, men's wages, etc., losses which are going on all the time, whether the engine is running or not. To make a correct comparison, we would, therefore, first of all, have to determine this constant loss—for instance, by test—and to calculate therefrom the total loss per year; then add the additional expenditure for useful work during 2,000 hours, and divide the total by the yearly output.

If we carry out this calculation, adding the capital cost (interest and depreciation) we arrive at a figure which is an indication of the economy of the installation. If the yearly output of the colliery decreases, the cost of winding per ton will rapidly increase, and so much more so the greater the constant loss. If we take the average number of winds per day of 250 working days, it will generally be found that the winder works far below its rated capacity; in other words, winders are generally too big for the work they actually have to deal with. There are some very good reasons for putting in too large winders, but as a result in many cases the constant losses increase to such an extent that their value becomes more important than the efficiency at full work; in other words, it might be more necessary to know what the winder is doing when standing, than to know what it is doing when running on load, and this point is altogether neglected in Mr. Mountain's paper.

As regards electric winding, for reasons stated above there are a good many cases where electric winding would be more economical, although if the comparison is extended only over eight hours of full work the steam winder appears to be by far the more favourable. In cases of direct winding there are no constant losses to be considered at all if we put the cost of current into our calculations at a fixed price. When using an Ilgner winder the constant loss is equal to the energy required to keep the motor generator running light. By suitable arrangements this loss can be reduced to a very small amount, so small that in many cases this alone would prove the superiority of electric winding over steam winding; but if we enter upon the question of electric winding we have also to consider the other requirements of the colliery. As a fact, nowadays the position of the problem is as follows: The power demands for underground work necessitate introduction of electricity at the collieries. The question is then if, having an electric installation of a certain output, it would pay also to have electric winding; to answer this question it will always be necessary to go closely into the details of the arrangements of the individual colliery in question, keeping the probable future demands in view.

Mr. Barnes. Mr. J. S. Barnes (*communicated*): I notice that the 3-phase alternators are driven by means of steam engines of the slow-speed horizontal type, but in installing electrical plant for collieries of a large output, the numerous advantages of turbines, as regards economical working and satisfactory running, should not be overlooked. The floor space

occupied by these engines and the alternator sets is considerable, viz., 0·65 and 0·96 sq. ft. per kilowatt, whereas with a Parsons steam turbine and a 3-phase alternator the floor space per kilowatt does not exceed 0·2 sq. ft. for large sets of 1,000 k.w., and for smaller sizes, up to 500 k.w., from 0·3 to 0·4 sq. ft. At Mainsforth Colliery, where we are installing three Parsons turbines with a capacity of 1,200 k.w., the actual floor space per complete set of turbine, alternator and exciter, is 130·6 sq. ft. This equals 0·32 sq. ft. of floor space per kilowatt of combined set. It appears from this that a power-station building equipped with horizontal engines and 3-phase slow-speed alternators must be two to three times larger than one in which turbines are used. Mr. Barnes.

The steam pressure, 120 lbs. per sq. in., is low for a modern equipment. At Mainsforth Colliery we have 8 Babcock & Wilcox boilers, working at a pressure of 200 lbs. per sq. in., and superheated to 520° F. They give every satisfaction, and are more efficient than low-pressure and low superheated steam.

The switchboard at Aberdare seems excellent as regards the safety of the attendants and the running of the plant. I see that the circuits have ampere and watt-hour meters. For 3-phase lighting circuits, it is essential to install three wattmeters on these circuits on account of the phases becoming unbalanced, but in view of the extra complications it is a question whether it is worth the cost of the meters, as the lighting is only a small portion of the total output. For lighting circuits it is always preferable to have an ampere-meter for each phase, so that the out-of-balance current can be readily detected ; for power circuits fed direct from the main only one ampere-meter, for the middle phase, is necessary, as all the phases are equally loaded, but when the centre of the system is earthed, it is important that three ampere-meters should be used per circuit, viz., one for each phase on power circuits, because, should the insulation of one of the cables break down, one ampere-meter alone would not necessarily show the overload caused by the "earth." The generator should, preferably, have integrating wattmeters and the circuits indicating wattmeters.

Taking the given coal consumption of 2·7 and 3 lbs. per unit delivered, and assuming that 8 lbs. of water are evaporated per horse-power-hour, or 10·72 lbs. of water per kilowatt-hour, we obtain 28·9 and 32·1 lbs. of steam per kilowatt-hour. This is unsatisfactory, as turbines do not consume more than 18 to 20 lbs. of steam per hour, with superheat and condensing, and 10 per cent. more without superheat and non-condensing, for 750-k.w. and 1,500-k.w. sets. It would be interesting if Mr. Sparks would give the data of the formula used in designing his cables, showing how he arrived at the sections of copper in the feeders, and how he arrived at the maximum voltage drop of 10 per cent. The construction of the overhead equipment seems excellent. Are the cables carried over or under the public roads? Are there lightning arresters connected to the overhead lines, both at the power station and at the substations? The 3,000-volt armoured cables going down the four pits, and extending a distance of 700 yards from the pit bottom, although within the limit of the recent

Mr. Barnes. Mines Act, should, I think, be kept aboveground. There is no great advantage in carrying high-voltage lines in the mine, and there is risk of breakdowns, on account of the rough conditions to which underground cables are subjected.

I presume the fourth wire of the distribution is dispensed with, because the neutral point of the star is earthed. I should prefer to run the fourth wire for lighting and dispense with the earth connection, as this enables better tests of the insulation to be made. I am referring only to the secondary side of the transformer. With regard to the gears, it is preferable to use rope or belt driving, instead of spur gear, as the latter takes up the shock of the heavy overloads, especially on large motors, and reduces the risk of leakage from the motors to the machinery. Why are 2-phase motors used for hauling instead of 3-phase motors?

Mr. Sparks. Mr. C. P. SPARKS (*in reply*): As most of the contributors to the discussion have touched on more than one point, I have grouped my remarks under the several points raised.

Pressure.—It is suggested that high-pressure should not have been used below ground on score of the greater safety and reliability of low-pressure. I am in agreement with Mr. Patchell's views on this point, but I entirely disagree with the advocates of low-pressure for underground work where a large power is required; first of all, large motors had to be supplied, some of the haulages requiring 300 to 400 B.H.P., while provision had to be made for pumps exceeding this power. With sub-stations above ground the cables may be $1\frac{1}{2}$ miles long before the point of power application is reached, which makes it uneconomical to work induction motors satisfactorily at 500 volts. The essence of success in colliery work is to have a steady and an even pressure when starting the motors. Where we have met a difficult drive the difficulty has been easier to surmount through having large generators and high-pressure cables, which have enabled us to keep up the pressure at the motor terminals at starting. This could not be done with low pressures. Then with regard to the question of safety: in my opinion, 200, 300 or 500 volts, with a large current, is far more difficult to control than a high pressure with a comparatively small current. Not only in mining work, but above ground, the general difficulties of distribution are much greater with low than high pressure mains. In cases where street explosions occur you will find on investigation that it is not the 10,000-volt or the 2,000-volt main that has caused the trouble; it is always the low-pressure main. The lower the pressure, the more dangerous it is from the point of view of explosion.

Frequency.—Fifty cycles was selected in place of 25, as the former is the standard in England and on the Continent; in consequence, 50-cycle motors are somewhat cheaper, and can be obtained more quickly than 25-cycle motors.

If the whole of the motors had been very large, slow-speed 25 cycles might have been selected, but the average size required was below 150 B.H.P., 290 revs., up to which point there is no

advantage in cost or efficiency through using the lower frequency. Mr. Sparks.
On the other hand the lighting can be supplied through static in place of rotary transformers, and the cost of the transformers for the 500-volt motors is somewhat lower at 50-cycles than 25-cycles for transformers of equal efficiency.

Earthing.—Mr. Ram raises the question of safety. The Powell Duffryn Company, although they had not the Home Office Rules before them when putting the work in hand, have not spared expense where they could see added safety for their employees. Many people suggest that electricity is a dangerous agent; but when one considers the risks run in collieries, and the fearful death-roll there is in this trade, I think we may claim that electricity is going to give added safety to the employees, and the few fatal accidents there have been are nothing compared with the enormous death-roll that has to be faced in this industry.

The "earth" connection, where possible, is made to water mains, and when these are not available to an earth-plate, 4 ft. square, buried in damp soil. The catchers on the transmission line are connected to an earth wire carried down and coiled at the base of the pole, the earth wire being shielded by a scantling 7 ft. from the ground.

Size and Type of Unit.—When the design of the power station was under consideration in 1903, turbine generators were considered, and slow-speed engines were selected as being more suitable for colliery work, primarily due to their reliability and the fact that the colliery mechanics were used to handling this type of plant.

A comparison has been drawn between the coal consumption of the 1,500-k.w. set of 2·7 lbs., it being suggested that turbines would require 33 per cent. less fuel. The comparison is incorrect, as the consumption given for the slow-speed set includes all losses in auxiliaries, whereas the turbine figure is calculated on another basis. The statement that a noncondensing turbine without superheat would only require 19·8 lbs. of steam (18 lbs. plus 10 per cent.) is quite incorrect.

Some criticism has been made of the size of unit selected. When the power house is complete the station will have two 1,500-k.w. and two 750-k.w. units, the two smaller units being able to replace either of the bigger ones, the station being worked with two 1,500-k.w. sets or two 750 and one 1,500-k.w. set. If we had been able to proceed with the entire equipment in the first instance, we might have put in three 1,500-k.w. sets, but we should still have been met by the difficulty that during two-thirds of the running hours we should have to use a 1,500-k.w. set working at one-quarter load. The 750-k.w. unit with 25 per cent. overload is a large unit compared with what is usually put down for industrial purposes in this country, and although the small unit in this case, it is relatively big compared with what is usually done.

Switchboard.—The scale of Fig. 2 is one-eightieth; each switch panel, which is separated from the neighbouring panels by fire-proof

Mr. Sparks. division, is 2 ft. 10 ins. in width, which allows sufficient room to get at the fixed contacts when the section switch is put on the trolley and wheeled away. The bus-bars and fixed contacts require a minimum of attention, as the circuit cannot be opened when current is passing through the contacts. If it is necessary to carry out any repair on the bus-bars the power station has to be shut down, as it has not been thought advisable to provide the bus-bars in duplicate.

The switchboard in the power house controls 3-phase supply only. At the sub-stations the lighting supply is given through a single-phase transformer connected across two of the phases. The connections to these lighting transformers are permanently made, and no attempt is made to balance the lighting load, as the power required for lighting is relatively a small proportion to the total, a sufficiently good balance being obtained by connecting the lighting-transformers across one pair of phases at one sub-station, and another at a second, and so on, the lighting supply being maintained from an independent set of low-tension mains.

Overhead Transmission.—The high-pressure mains are protected by lightning arresters at the power house and at each sub-station; the low-pressure mains at the sub-stations. The high-pressure lines are overhead at all points except where they leave the sub-stations to enter the mine shafts. Some four hundred poles have been used in constructing the transmission lines. We have had some severe storms, including thunderstorms, since the transmission lines were erected in the spring of 1905. The thunderstorms so far have not troubled us. In one exceptional gale accompanied by sleet we had trouble, which has been cured by putting in extra poles.

The B.H.P. of motors fixed at Lower Duffryn has been increased since the original lay out by the transfer of motors from other pits. Up to now the diversity factor has enabled the supply to be maintained here without exceeding 10 per cent. drop in pressure. With a further increase in the number of motors it has been decided to duplicate the route to Lower Duffryn, *viâ* the George Pit, which will give a supply to a further pit, and at the same time duplicates the supply to Old Duffryn, Lletty Shenkin, and Lower Duffryn pits.

Cables.—Several of the speakers have objected to the use of lead-covered paper cables. The only alternative at present available is to sheath with bitumen, which is unsuited for shaft work. With the lead sheathing there is undoubtedly a risk of the metal being eaten away if the pit water is corrosive. In my opinion the deterioration is one that must be faced by the colliery proprietor, as the use of the lead-covered cable increases the safety of the employees. It has been suggested that three separately insulated low-pressure cables encased in wood are better suited for shaft work. I entirely disagree with this suggestion. With any form of cable avoiding the mechanical sheath a partial leakage may take place which is not sufficient to bring out the "automatic" or blow the fuse, which results in a distinct danger to life. In my opinion such a system

should be prohibited, as, although the partial leakage would not prevent working, it might kill several of the employees in the pit. Mr. Sparks.

Haulage Gears.—As electric motors had to be fixed to existing haulage gears, replacing the steam engines, it was not possible to consider rope driving, as this would have necessitated reconstructing every haulage engine house. Provided a moderate speed is selected, there does not appear to be any necessity to adopt rope driving to minimise strains on the motor. If the supply was derived from a small power house, rope driving undoubtedly presents advantages.

In carrying out the conversion of haulages, these have, as far as possible, been put under ground to avoid the up-keep of the rope and the friction loss in the shafts. I have no figures as to the exact saving due to this, but it is of sufficient importance to warrant the fixing of all haulage motors under ground if it can possibly be arranged. As occasion arises the existing haulage motors above ground will be re-erected below.

It has been suggested that the haulage gears should have been driven with two motors, preferably continuous current. Continuous current could not be considered, having regard to the area dealt with. The use of two motors has a considerable advantage from the point of view of stand-by, but the capital cost of such an arrangement more than outweighs such advantage. I have not found the haulage motors unreliable, and if you split up 150 B.H.P. motors into two of half this size it lowers the efficiency and the power factor of the system.

Particulars of gearing given in Table V. and on page 492 have been corrected. These, as pointed out, are not in agreement with the details given. The speed with the gears as given (Fig. 10) corresponds to 5 miles per hour with the drums empty.

Fans.—The question of speed regulation was considered at an early stage, and it was found with a fan not working up to its full capacity, where the district was just opening up, that it was cheaper to put in a small motor at the start, and eventually to put in a larger motor, transferring the small one to some other duty. In the case of a fan approaching its full duty, pulleys were arranged so that the speed of the fan could be raised to the full duty by altering the pulleys in the future. In most cases dealt with the fans were working at their full duty, and, therefore, the question of speed regulation had not to be tackled.

Cost of Power.—Assuming the correctness of the curves put in by Mr. Addenbrooke, they show there is little probability of a power company being able to supply an undertaking as large as the Powell Duffryn, as with the increasing output the costs dealt with in the last page of my paper would fall below 0·3d., which figure would only just be reached, according to the table, if the supply were given from a 60,000-k.w. power station, which would only be required if from 150,000 to 200,000 H.P. of motors was being supplied for industrial purposes from one centre.

Mr. Mountain suggests that the present working costs of 0·365d.,

Mr. Sparks. including interest and depreciation, represents the cost at which energy could be produced without difficulty in almost any colliery. I disagree with this general conclusion; unless the load factor is higher than that given in my paper, if all items of cost are taken into account, the average cost to a single colliery will much exceed the figure given.

Mr. Vesey Brown suggests that certain extra costs should be included to compare with the costs where power is taken from the power company, but as the costs of items 1 and 2 are incidental to the power supply, they would be borne by the power company, and must not be added to the costs borne by the colliery proprietor.

Tests.—Mr. Bloemendal asked for tests of power or coal consumption for the different motors. I have given figures of the energy taken in certain cases. It is not possible to take any coal consumption tests, as once the power station was started it was impossible to disconnect and make a special test on one part of the system; that is to say, we could not run one fan or one pump; we have to supply the general wants of this group of collieries.

Coal Consumption.—Mr. Patchell referred to the figures I recently gave him dealing with the B.Th.U. required per watt-hour. As the station started in May, 1905, the figures were not based on twelve months' working. The power load of a colliery being very similar in summer and winter, the figures were substantially correct. The figures as under were not test figures, being based on six months' working:—

Units delivered to mains	4½ millions.
Load factor...	37 per cent.
Average calorific value of fuel	13,000.
B.Th.U. per watt-hour	49·0.

Electric Locomotives.—I have not sufficient mining experience to say that there is no application for these in England, but from what I have seen in South Wales collieries I do not think there is any possibility of applying locomotives there. The question of contact alone puts this out of the question. Even if the ways were sufficiently high it would be unsafe to use a trolley, and the first thing that the mine manager looks at is the question of safety.

Coal Cutting.—It is not the intention to use electric coal-cutters in working these pits; compressed air coal-cutters are in use, and any further extension of these will be supplied by electrical air-compressors fixed in well-ventilated situations in the mine.

Several speakers have referred to the value of the publication of detailed information, usually difficult to obtain. My best thanks are due to Mr. J. Shaw, Chairman of the Powell Duffryn Company, and to the Directors for having allowed me to publish the detailed information of the work I have carried out for them.

Mr. Mountain. Mr. W. C. MOUNTAIN (*in reply*): Perhaps I had better reply, as far as I can, to Mr. Patchell's remarks first. He very kindly pointed out one or two small errors, and of course I shall be only too glad to try and correct anything which may be wrong. In one of them, referring to

Mr. Mountain.

Messrs. Richard Evans & Co., it is quite correct that the number of winds shown does not quite equal the quantity of coal; but as a matter of fact, two tests were made at Messrs. Richard Evans', one with a balance rope and one without a balance rope. With a balance rope we wound 1,260 tons with the same consumption of coal as we wound 1,080 tons without the balance rope, which clearly shows that we wound 15 per cent. more coal with a balance rope than without. With regard to the tests at the Sherwood Colliery, Mr. Friar wrote to me and pointed out an error, but I could not quite follow his figures. I read the letter at the Manchester meeting, and it should have been reported, but it was not, and I have never seen the notice in the paper that Mr. Patchell referred to. If it appeared, it appeared without my knowledge, otherwise I should certainly have acknowledged it here.

In reference to the figures for the Zollern plant given in the paper read by Mr. Hooghwinkel, I am not aware that I gave any figures in my paper in connection with the Zollern plant. I merely mentioned that, judging by the appearance of this plant, including its share of the generating plant it probably cost about £20,000. I would like it to be clearly understood that my only object in writing the paper (to which Mr. Hooghwinkel's was a reply) was to endeavour to bring such facts and figures forward that could be grasped by the non-electric mind of the mining engineer or colliery manager, and further, that these figures should be so grouped that they were open to full criticism from both sides. I visited Germany in order to convince myself that there was some considerable economy to be obtained by adopting electric winding in collieries where the steam required for working the winding engine was produced by boilers close to the winder, and also in collieries where they were winding from one or more main shafts. These are the conditions under which the bulk of the large winding engines in this country will be required to work in the future, unless, of course, power companies come forward and offer to supply current at a price which would enable the colliery-owner to utilise the current for winding economically. The conclusion I came to—after inspecting the large installation at Zollern II. and also the installation at Preussen Colliery (the former being on the Ilgner system and the latter by 3-phase current direct at a high voltage)—was that neither system presented any possibility of competing against really high-class steam engines for heavy work, and I consider that I am only doing my duty to the mining profession and also the electrical industry in telling them honestly and straightforwardly my conclusions.

The figures which I have prepared have involved a large amount of time and work to get together, not only as regards information obtained from the thirteen collieries given in Table I., but also the examples of high-class steam winding in Tables II., III., and IV., and Table V., which gives my estimated cost of electrical winding gears, to compare with the examples of steam winding. In considering the application of electric winding many points have to be taken into account, such as:—

Mr. Mountain.

A. Cost of coal.
B. Depth of shaft.
C. Speed of winding.
D. Total output.
E. Total winding time per day.
F. Whether it is convenient to use balance ropes.

It is therefore quite impossible to make any definite statements, such as I have been repeatedly asked to do, namely, for what depths it was convenient or economical to adopt electric winding.

Mr. Hooghwinkel has criticised the figures which I have given, and I am glad that many other members of the Institution have also done so, because it is only by a careful consideration of all the points that we can arrive at any accurate decision. Unfortunately, Mr. Hooghwinkel has, I am afraid, made some errors in his table of comparison between the winding cost at Zollern and my figures. It must be borne in mind that the Zollern electric winder is designed for an output of 1,350 tons 330 yards deep in eight hours, but I understand that the plant is capable of dealing with about this quantity of coal up to a depth of about 550 yards, so that Zollern may be taken as very nearly representing my example of an electric winding gear to wind 1,500 tons from a depth of 500 yards. The errors which Mr. Hooghwinkel has made are as follows:

In my paper (Table V. Example II.) it is stated that the weight of coal per wind is 3·6 tons. Mr. Hooghwinkel wrongly quotes it as 3.

The number of winds per shift of eight hours was given as 417 for two shifts; twice 417 should be 834, and not 1,000.

The weight of cages I stated as 5·5 tons. Mr. Hooghwinkel gave 3 tons.

The time of winding was stated as forty-nine seconds. Mr. Hooghwinkel gives it as fifty-seven seconds.

The consumption of coal on two shifts of eight hours should be 11·5 tons, not 8·5.

The cost of coal was given by me as 3s. 6d. per ton. Mr. Hooghwinkel bases his estimate upon 2s. 6d., so that to wind 100 tons the cost of coal should be 11½d., not 1s. 4d.

The result of adjusting these figures is that the total cost of winding per 100 tons, without interest and depreciation, should be 2s. 7d.

My figures were all based on the assumption that the plant only ran for eight hours per day, but if the interest and depreciation has to be spread over two shifts, then the cost per 100 tons after adjusting the figures would be as follows:—

Zollern II. per 100 tons, eight hours' shift, per Mr. Hooghwinkel, 9s. 9¾d.—Mr. Mountain's example per 100 tons, 11s. 3d.; Zollern II. on eight hours' shift according to Mr. Hooghwinkel, 6s. 1¾d.—Mr. Mountain's example, 6s. 11¾d.

It will be noted from Table D, which I give, that the real point between us making up the very slight difference which exists is the amount allowed for labour. I consider Mr. Hooghwinkel's

Mr. Mountain.

TABLE D.

	Zollern II. (2).	Mr. Mountain's Example.	Zollern II. 2 Shifts (Actual).	Mr. Mountain's Example (2 Shifts).
Coal wound per day of eight hours	1,350	1,500	2,400	3,000
Depth of shaft in yards ...	330	500	330	500
Weight of coal per wind, tons	4·6	3·6	4·6	3·6
Number of winds per day of eight hours	260	417	521	834
Weight of cages and slings, tons	3·5	5·5	3·5	5·5
Time of wind in seconds ...	—	49	—	49
Time for changing in seconds	—	19	—	19
Total time of wind, including changing, in seconds ...	104	68	104	68
Max. speed at present, in feet per second	35 (?)	36	35 (?)	36
Coal burnt per day of eight hours in tons	3·0	5·75	5·0	11·5
Cost of coal burnt, 2s. 6d. per ton	7s. 6d.	14s. 5d.	12s. 6d.	28s. 10d.
Per 100 tons wound	6¼d.	11½d.	6¼d.	11½d.
Cost of winding plant ...	£10,000	£10,500	£10,000	£10,500
Total cost of proportionate part of generating station	£4,000	£5,700	£4,000	£5,700
Wages per 100 tons wound :				
Stokers	11½d., including oil and stores	6½d.	11½d.	6½d.
Ashmen		—		—
Generator attendant ...		5d.		5d.
Winding engine man ...		5d.		5d.
		1s. 4½d.		1s. 4½d.
Working days per year ...	250	250	250	250
Total cost of winding per 100 tons	1s. 5¾d.	2s. 7d.	1s. 5¾d.	2s. 7d.
Total cost, including interest at 5 per cent., depreciation 5 per cent., on eight hours winding day	9s. 9¾d.	11s. 3d.	6s. 1¾d.	6s. 11¼d.

allowance is far too small to meet the conditions in this country. I also consider that Mr. Hooghwinkel's coal consumption is too low to be safe. I have based my consumption throughout on 25 lbs. per kilowatt-hour, which means about 15 lbs. of steam per indicated horse-power of the engines, and this is in my opinion low enough, considering that steam has to be provided for the feed pumps and also something for the condensation in the steam-pipes and other losses.

Where I think Mr. Hooghwinkel has gone wrong in his comparative estimates is that, instead of adding his depreciation on the plant of eight or sixteen hour shifts, he has simply taken the depreciation over a year of 365 days, and added the proportion due to the short time that the winding engine is working. This, of course, is an incorrect

Mr. Mountain.

method, but it has the effect of making the amount for depreciation very much smaller than the amount which I have provided, and which I think it will be agreed is the correct way.

Mr. Hooghwinkel then gives another example of the electric winding at the De Wendel Colliery, this colliery being equipped with electric winding plant to deal with 1,400 tons in eight hours 770 yards deep. When Mr. Hooghwinkel's paper was discussed in Newcastle, I assumed that the figure representing the cost of the electrical plant included a proportion of the cost of the generating plant, but in his reply Mr. Hooghwinkel stated that the sum of £15,000 which he quoted was the cost of the electric winder only, together with balancer. If you will compare this figure with my estimated figure of the cost of winding 2,000 tons per day of eight hours from a depth of 700 yards, namely £14,200, you will see that, instead of my prices being high, they are as a matter of fact much lower than the costs quoted against me. At the De Wendel Colliery it appears that the coal used for fuel under the boilers is very cheap, namely 1s. 6d. per ton; but notwithstanding this fact, the paper states that the cost was 6s. per 100 tons. The cost represents, I understand, the cost of electrical energy from the power station, but to this must be added the wages of winders, including oil, etc., amounting to 6d., making the total cost 6s. 6d. Mr. Hooghwinkel has apparently omitted interest and depreciation in his cost of 6s. 6d. per 100 tons, and then only proposes to add interest and depreciation on £5,500, namely, the difference between his estimated cost of steam winding and electric winding plant; but this, of course, is an incorrect method of calculating, because the interest and depreciation must be added on the full value of the electric winding gear. At 10 per cent. per annum the interest and depreciation on £15,000 is £1,500 per annum, or on 250 days winding per annum, £6 per day, or 8s. 8d. per 100 tons. Adding this to the original cost of 6s. 6d. brings the total cost of winding at De Wendel to 15s. 2d. per 100 tons.

Mr. Hooghwinkel has produced a list of about forty collieries equipped with electric winding plant, but the bulk of them are for very small outputs, and it is conceivable that under these circumstances electric winding can be economically adopted, but it would have been much more interesting to the Institution if in each case the actual cost of these plants had been stated, and the cost per 100 tons wound worked out on the same basis as I have done in my paper.

Mr. Hooghwinkel gives the figure of 50 lbs. of steam per useful horse-power hour as the best result to be obtained from high-class steam winding engines. This figure, however, is much in excess of what Messrs. Fraser & Chalmers and other makers of high-class steam engines will be prepared to guarantee, and further, the figures, which I shall give later, and also the figures taken on the test both at Sherwood and Atherton, prove that such figures have been obtained in practice. To my mind the term useful horse-power conveys very little of value to the mining engineer, because it does not take into account the actual horse-power which is required to accelerate, and what will appeal to the mining engineer is the cost of winding from his shaft per

100 tons. In Mr. Hooghwinkel's paper and also in my own, provision is made for one generating plant, or the proportionate cost of the generating plant due to winding. In doing this I assumed that electric winding is not likely to be adopted in any collieries where it is not proposed to drive everything else electrically. In my opinion, it would not be safe for any colliery-owner to depend on one engine and generator only for such important work as winding, and a stand-by set would undoubtedly be required. Mr. Mountain.

Mr. Hooghwinkel then mentioned the extra safety of electric winding. I consider that such a statement is liable to render us the laughing-stock of the mining profession. I am quite prepared to admit, and I honestly believe, that electric winding is very safe, but it must be borne in mind that between the engine and the winding drums there are a dynamo, switchboard, cables, motor, heavy flywheel (running in two bearings), generator, switchgear, and two electric motors on the winding engine, all of which are liable to go wrong. It is quite true that if well constructed the risk is small, but the liability still exists. Mr. Hooghwinkel also talks about improved acceleration, also overwinding devices and general safety appliances. As regards acceleration, there is no doubt that the steam engine, owing to the enormous power which can be put into the cylinders at starting, will accelerate more quickly than an electric winder, and the figures which Mr. Clift has produced, and to which I shall refer later, will confirm my views. Possibly Mr. Hooghwinkel does not know that every modern steam winding engine is fitted with the whole of the safety appliances used on electric winding plants.

When I referred to the suitability or otherwise of electric winding, it must be borne in mind that my remarks only apply to heavy winding, such as we are likely to require in new collieries in the future; and, as an example of such work, I would refer to the table given herewith which represents three modern winding engines which are at work, or being erected, in Yorkshire at the present time; but my remarks would also apply to electric winding engines of about the capacities stated in my paper, namely from 1,000 tons to 2,000 tons per day of eight hours, and I feel confident that for such heavy work, unless the circumstances are very exceptional and the cost of coal is considerable, steam winding will be found the most economical. These remarks apply to collieries so circumstanced that each colliery requires its own winding engine with boilers in close proximity.

The figures which I quote in reply to Mr. Clift's criticism seem (even assuming the cost of electric winding plants can be reduced to his figures, which I doubt) to point to the fact that, with coal at about 10s. per ton, there is every prospect of electric winding being economical, but, as I pointed out in my first remarks, there are many collieries in which the value of the coal burnt under the boilers is practically nil, and where, if they were not able to burn the dust and coal themselves, it would have to be carted away or else put on the pit heap at considerable expense and with every prospect of spontaneous combustion. There is no doubt that the Koepe system very much assists

Mr. Mountain.

the electric winding problem, but it is unfortunately not in favour in this country, principally due, I think, to the feeling that if the rope broke both cages would fall to the bottom of the shaft, causing considerable damage. The use of heavy parallel or conical drums in favour in this country makes the horse-power required for acceleration very great, and, of course, it is upon the use of such drums that my estimates are prepared. The further discussion which has taken place, and which I fully welcome, has been principally directed to show that my figures are wrong, and Messrs. Siemens Bros. are now producing figures which they apparently have arranged in comparison with my steam figures, in connection with the estimate for winding 2,000 tons in eight hours from a depth of 700 yards. Mr. Clift, I consider, was not justified in the remarks which he made with regard to the information which his firm were supposed to have given me in connection with their electric winding schemes. I have been carefully through my correspondence, and the figures which were supplied did not enable me to compare the costs with the typical examples which I produced. To compare the figures which are being produced before the Institution, it is rather interesting to note that Mr. Hooghwinkel estimated the Zollern plant as costing £10,000 to wind 1,350 tons from a depth of 330 yards at present, to be extended to about 590 yards later on.

My estimated figure of a plant to wind 1,500 tons 500 yards deep was £10,000.

Mr. Hooghwinkel gave also the figure of £15,000 as representing the value of the electrical plant at De Wendel Colliery, which, according to his statement, is supposed to wind 1,400 tons per day from a depth of about 700 yards. On reference to my estimate, it will be noted that I give the cost of a plant to wind 2,000 tons per day 700 yards deep at £14,200, and I can only assume that Mr. Hooghwinkel's figures are correct. It is rather interesting with these figures before us to note that Mr. Clift has adjusted the figures in order to suit the circumstances, and that he now estimates the cost of a winding plant, with balancer, to wind 2,000 tons 700 yards deep at £9,000. In order to do this he proposed to run his balancer at 50 per cent. higher speed than I do, namely, 465 r.p.m. against 300 r.p.m., and to reduce the weight of the flywheel from 67 tons to 28 tons. Another point is the question of the steady running horse-power. I have estimated 1,000, whereas Mr. Clift, by adjusting his acceleration, and, I think, cutting things far too fine, brings his horse-power to 910 as the steady running horse-power of the motor.

Apparently Mr. Clift's motor is of 100 per cent. efficiency, as he gives the kilowatts as 680, whereas, taking the motor at 90 per cent. efficiency, the actual kilowatts should be 750, which very nearly approaches the figure given in my estimate of 800 k.w. input into the motor terminals.

Mr. Clift has also reduced the number of boilers from four of 8 ft. 6 in. diameter by 30 ft. long to two of 9 ft. diameter by 30 ft. long, but the boilers are very nearly alike, and I do not think that when burning the ordinary coal which is available in most collieries one

would expect to get from two boilers of this size, with any margin, sufficient steam for 800 k.w., which is equivalent to approximately 1,300 indicated H.P., because it must be remembered that in all large boiler plants of this kind it is necessary to provide some sort of a spare, and whilst I think that three boilers of this size might safely be installed, I think that two would be too few. The price at which these are put in, namely, £1,000 per boiler, which has to include all steam and exhaust pipes, feed pumps, getting the boilers to site, erection, and the proportion of the cost of a central condensing plant, is, in my opinion, too small a sum. The same remarks apply to the amount allowed for the generating plant ; about £3 per kilowatt is too low. Mr. Mountain.

An example which Messrs. Siemens gave me as a typical winding gear was the Stinnes plant, which, according to their information, is of the following capacity :—

Depth of shaft at present	550 yards
Depth of shaft later on	866 yards
Capacity per hour	100 tons
Capacity per day of eight hours... ...	800 tons
Winding speed in feet per second ...	46
Type of winding drum	Koepe
Capacity of converter motor	500 H.P.
Weight of flywheel	54 tons
Capacity of converter generator ...	2,000 H.P.
Diameter of Koepe pulley	6·5 mètres=21 ft.
Normal horse-power of the two winding gears	1,220
Maximum horse-power	2,000
Speed of motors	42 revs.

From these figures it will be noted that whilst in Germany it is apparently necessary to have a maximum of 2,000 H.P. to wind 100 tons per hour from a depth of 860 yards, in England it is only necessary to have 1,700 maximum H.P. to wind 250 tons per hour from a depth of 700 yards, and this although in Germany the Koepe wheel is used, which takes very much less power to accelerate than the parallel drums in use in England.

The plant, particulars of which are given above, is only a little more than half the capacity of my estimated plant for 1,500 tons 500 yards deep, and they estimated the cost of it, in the particulars which they gave me on October 27, 1905, at £10,000.

We will now consider the De Wendel plant on the same basis. The capacity of this plant is apparently as under :—

Tons per hour	175
Tons per day of eight hours ...	1,400
Depth of shaft	820 yards
Maximum winding speed	29 ft. per sec.
Type of drum	Koepe pulley
Capacity of converter motor ...	950 H.P.

Mr. Mountain.

Weight of flywheel	54 tons
Capacity of converter generator ...	2,700 H.P.
Diameter of Koepe pulley ...	6·4 mètres = 21 ft.
Normal horse-power of the two winding gears	1,620
Maximum horse-power of the two winding gears	2,700
Speed in revolutions per minute ...	54.

From these figures it will be seen, and I presume that they are correct, that in Germany it takes a maximum of 2,700 H.P. to raise 1,400 tons 820 yards, whereas in England Mr. Clift can apparently wind 2,000 tons 700 yards deep in eight hours with 1,700 H.P. I venture to say that, if the information which Mr. Clift has sent me is correct, it proves that the whole of the figures which he has supplied to this meeting to refute mine are absolutely incorrect, as the German figures entirely support my own estimates of horse-power for acceleration and steady running, also for cost.

After Mr. Clift has so twisted my figures and altered his own that he has brought mine down to what he considers will suit his case, and then adjusted his own costs of plant, it is extraordinary that he is not able to say that with coal at an even price, namely 3s. 6d. per ton, he can do any better with his electric winding than can be done with high-class steam winding.

On reference to the table drawn to show the comparison between Mr. Clift's figures and my own, it will be noted that the costs are as under, in each case winding 2,000 tons 700 yards deep in eight hours:—

	£	s.	d.
Mr. Mountain's calculated cost per 100 tons for electric winding, with coal at 3s. 6d. per ton ...	0	12	5
Mr. Clift's ditto....	0	8	2¾
Mr. Mountain's estimated cost for winding with steam in seven and a half hours, with coal at 3s. 6d. per ton	0	7	2½
Taking the full capacity from engines, namely 2,182 tons, with coal 3s. 6d.	0	6	9¾

Mr. Clift then takes out cost of winding and increases the value of the coal to 6s. and 8s. per 100 tons. The correct comparison is then as follows:—

	£	s.	d.
Mr. Clift's estimated cost per 100 tons with coal at 6s. per ton	0	9	3
Mr. Clift's estimated cost per 100 tons at 8s. per ton	0	10	0½
Mr. Mountain's on full capacity of engine, namely 2,182 tons at 6s.	0	8	5¼
Mr. Mountain's on full capacity at 8s.	0	9	9

These figures speak for themselves.

The estimates which I have made up of the cost of the electric winding plants have been carefully calculated, allowing a reasonable

Mr. Mountain.

and fair margin to insure satisfactory working, and the prices at which the various parts composing the estimate have been put in are, in my own opinion, fair market prices, and I do not believe that they can be very much reduced, at any rate with the existing state of knowledge on the subject, if a satisfactory installation is to be provided.

I would call your attention to the weights of the flywheels, namely :—

Zollern	45 tons, running at 345 r.p.m.
Stinnes	54 tons, no speed stated.
De Wendel ...	54 tons, no speed stated.

But I assume that the speeds must be somewhere about the same as Zollern, and I ask you to compare what is found necessary in Germany with what Mr. Clift proposes in England.

The Electrical Company gave me some figures of the Esperance Mine, and their figures are interesting as confirming my own calculations :—

Final depth of shaft...	875 yards
Present depth	404 yards
Tons per day of eight hours	512
Tons per hour	64
Load per journey	2·14 tons
Maximum speed of winding	33 ft. per sec.
Number of tubs	4
Weight of tubs	1 ton
Weight of cage, etc....	1·8 tons
Size of Koepe wheel	10 ft.
Number of journeys per hour	30 (estimated)
Horse-power of motor on motor generator ...	250
Output of generator...	650
Weight of flywheel	40 tons
Diameter of flywheel	13 ft. 1½ ins.
Speed	285 revs.
Horse-power of winding motor normal	320
Horse-power maximum	615
Speed of winding motor	64 revs.

With this deep shaft and slow winding and small output, it shows that 250 H.P. is required at the motor generator to raise 512 tons in 8 hours from a maximum depth of 875 yards, and if these figures are compared with my smallest example, namely 1,000 tons 500 yards deep, it will be seen that the figures practically confirm mine. The Electrical Company gave me the cost of this plant as £10,000, *i.e.*, for the mechanical and electrical portion of the winder only, and it will therefore be seen that my estimate of £8,600 for a plant for 1,000 tons 500 yards deep is again well confirmed. As regards Dr. Herzfeldt's remarks in connection with the Grand Hornu Mines, I may possibly have misread this figure, but if he will refer to the appendix giving the particulars of the Grand Hornu Mines, he will find he gave me the following table :—

Mr. Mountain.

APPENDIX.

Grand Hornu Mines.

Working Costs per Kilowatt-hour at the Power Station.

Actual energy measured at switchboard per day of twenty-four hours: 16,000 k.w.-hours.

COSTS PER DAY OF TWENTY-FOUR HOURS.

1. Boiler-house	1 Chief Stoker 3 Assistant Stokers	15.25	francs.
2. Engine-room	2 Fitters 1 Assistant 2 Electricians	18.95	"
3. Oil and sundries		11.20	"
4. Coal, 21 tons at 5.5 fr. (4s. 4d.)		115.50	"
5. Repairs and maintenance		15.20	"
6. Interest * and amortisation † charges on capital (849,786 fr.)		171.40	"
		347.50	= £13 14s. 6d.

$$\text{Costs per k.w.-hour} = \frac{347.50}{16{,}000} = 2{\cdot}17 \text{ centimes} = \frac{£13\ 14s.\ 6d.}{16{,}000} = 0{\cdot}206d.$$

These figures apply to the working of No. 7 shaft winder only, and the daily output of the station will ultimately be raised to 24,000 k.w.-hours, when the second ventilator and the winder at shafts Nos. 12 and 9 are running normally. Assuming the items 3 and 4 to increase proportionally with the k.w.-hours generated—*i.e.,* the least favourable conditions—it is estimated that the costs per k.w.-hour will be as follows:—

$$\frac{410.85}{24{,}000} = 1{\cdot}71 \text{ centimes}$$

$$\frac{£16\ 4s.\ 6d.}{24{,}000} = 0{\cdot}162d.$$

I should like to point out that on referring to item 6, apparently interest and amortisation charges are calculated on a basis of 9 per cent. on the capital as given above, and that on this basis the cost per day of twenty-four hours, assuming 250 working days per year, should be 305 francs, and not 171.4 francs.

I again say it is possible to have misread the figures, but I cannot reconcile the figures with what appears to me to be the actual cost, as given in the following table:—

Tons per day of twenty-four hours	1,560
Depth of shaft	766 yards
Hours worked per day	24

* 4 per cent. per annum. † In twenty years.

Mr. Mountain.

Tons of coal per hour	65
Tons of coal per wind	2·6
Consumption of current per hour, 255 k.w. at 0·3d.	6s. 4d.
The cost of winding per 100 tons is therefore $\frac{6/4 \times 100}{65}$	= 9s. 9d.
Oil, grease, and stores	5d.
Winders' wages	1s. 2d.
Total	11s. 4d.

The figure of 0·3d. per k.w.-hour for the consumption of current does not agree with Dr. Herzfeldt's figure of 0·206d., but in arriving at his cost he is taking interest and depreciation at only 9 per cent., coal consumption per I.H.P.-hour only 1·8 lbs.—which is far too low a figure for ordinary collieries with only a small output during the night-time—and the wages of men only about 3s. per day.

These figures may be correct for a German colliery, but they certainly would not be so for an English one, and I have arrived at the figure of 0·3d. by taking interest and depreciation at 10 per cent., coal per I.H.P.-hour at 2½ lbs.—a much more reasonable figure—and English rate of wages for the men.

The figure of 11s. 4d. which I give above does not include interest and depreciation on the winding plant, but only on the generating plant, so that, taking the value of the winding plant, exclusive of ropes, cages, and headgear, but including labour fixing, at £4,000 (the figure given me without fixing was £3,800), we have to add to the above interest and depreciation on this sum at 10 per cent. per annum, which, working 24 hours per day and 250 days per year, amounts to 3s. 1d. per 100 tons, bringing the total cost up to 14s. 5d., and, of course, this cost would be very much increased if 16 or 8 hour shifts only were worked.

I am afraid I cannot quite follow the calculation of only 1·46 k.w. being required per effective horse-power. Assuming that the average demand on the generating station for this winding is even 350 k.w. (see diagram) and as the actual horse-power in the shaft or useful horse-power is 166, it would appear that it required 2·1 k.w. per useful horse-power, on the assumption that the changing is done in about the same time as in England, namely, from fifteen to twenty seconds.

The Electrical Company and also Messrs. Siemens have given figures of the estimated consumption of steam per useful horse-power. I have already stated that I do not consider that this method of calculation is worth the paper it is written upon, as regards the practical result, as it is not so much the value of the coal which affects the possibility of commercial winding as the heavy cost of the plant, but it is rather interesting to note that my calculated figures, which were based on 25 lbs. of steam per k.w., or about 15 lbs. per indicated horse-power, worked out as follows :—

1,000 tons 500 yards deep	35 lbs. per useful H.P.
1,500 tons 500 yards deep	34 lbs. „ „ „
2,000 tons 700 yards deep	34 lbs. „ „ „

Mr. Mountain.

The actual test at Zollern shows 31·35 lbs. per useful horse-power. I do not think in regular colliery work it will be safe to assume a less consumption of steam than this.

As regards my examples of steam winding, I may say that the whole of the consumptions are guaranteed by the makers, who are firms of high repute, but taking the figures which I gave, the consumption per useful horse-power is as follows:—

1,000 tons 500 yards deep	44 lbs.
1,500 tons 500 yards deep	39 lbs.
2,000 tons 700 yards deep	43 lbs.

The figures which Mr. Clift worked out of the steam consumption of similar engines, *i.e.*, Fraser & Chalmers at Atherton Colliery and Sherwood, and which he gives as 45 and 31 lbs. respectively, go to prove the correctness of the estimates which have been given by Fraser & Chalmers. Mr. Clift appears to have selected the worst possible example of steam winding.

I did what I considered to be the only honest thing in putting down every figure which I received, good or bad, and I will let people draw their own comparisons; but if Mr. Clift is not practical enough to recognise that a pair of engines with cylinders 36 in. diameter by 72 in. stroke with 80 lbs. of steam and wasting eighty-four seconds per wind for banking and waiting is not put forward as a typical example of economical winding, it is no fault of mine. To wade through a lot of figures like these is wearisome, but I do not think that any of the speakers have really put forward any claims which will justify the heavy expenditure for electrical plant for really heavy winding. I admit, as I have done in the whole of my remarks, not only in this meeting but elsewhere, that there is a considerable field for electric winding in small collieries and for small outputs, but I do not think that when coal is cheap, and where the steam has to be generated at the colliery and the winding is heavy, electricity can compete.

The general conclusions I draw as regards electric winding are as follows:—

1. For small collieries there is a future for electric winding if the coal used under the boilers is of any considerable value.

2. In large collieries there is a future for electric winding if the fuel or coal used under the boilers exceed 8s. to 10s. per ton.

3. Electric winding cannot be economically applied in collieries for very large outputs where the horse-power required for winding is greatly in excess of the horse-power required for driving the other machinery, both on the surface and underground.

4. In collieries generally, particularly those in which electric winding is adopted, colliery-owners will be well advised to take their current from the supply companies, assuming that they can purchase it at a reasonable price, even if this price is slightly in excess of what they can make the current themselves. The amount of capital required for the generating plant being so heavy, it could

usually be applied to much greater advantage in increasing the electric plant or improving other machinery about the collieries. Mr. Mountain.

Mr. Hooghwinkel. Mr. G. HOOGHWINKEL (*in reply*): Mr. Mountain's complaint that I had not reproduced his figures correctly is partly in order, as I took his figures from an abstract in the technical press, the original paper not being to hand. This small difference, however, viz., 3 tons of coal per wind, instead of 3·6 tons, is very unimportant, and does not affect the results at all. But it also changes the number of winds per hour, and the time per wind in proportion.

The figure of 3 tons for the cage was given, because Mr. Mountain gave this in his example for steam winding under the same conditions, and I thought that 5·5 tons, which is much too heavy, was a slip of the pen. There is, of course, no earthly reason why the cages should be heavier for electric winding than for steam—rather the contrary.

As these small differences do not affect the results, I gladly accept Mr. Mountain's corrected table, after correcting another of Mr. Mountain's slide-rule slips, viz., the last item in the first column, which should be 9s. 9¾d. instead of 10s. 9¾d.

This shows that the actual costs of electric winding at the Zollern Colliery, which is built for twice the present output, were nearly half the amount estimated by Mr. Mountain.

The capacity of the Zollern plant is 2,000 tons (not 1,350 tons) in eight hours from a depth of 550 yards. At present the winder is doing only 1,350 tons from 330 yards, winding at half speed. This explains, of course, the long time of banking in comparison with the actual winding time. The average speed is 20 ft. per second, which corresponds very well to the measured maximum speed of 35 ft. per second. In Mr. Mountain's example, however, the mean speed is about 30 ft., in which case the maximum speed will be nearer 45 ft. than 36 ft. per second.

Referring to the De Wendel Colliery, this plant is built for an average output of 1,500 to 2,000 tons from nearly 1,000 yards, although it is winding at present from only 770 yards. The cost of 6s. is the price charged by the power station (360 units at 0·2d.) and includes interest and depreciation for the power plant.

As to Mr. Mountain's list of steam-winding collieries, the results of which I have taken to be correct to compare them with the De Wendel and the Zollern Collieries per twenty-four hours' day, I have since ascertained from some of them (as I suspected these figures) that they are only during an actual winding shift, neglecting therefore the enormous standing charges of steam, etc., during the greater part of the night. They have little value, therefore, for comparison, and may be twice as much, or more, if taken per day of twenty-four hours. This is also in answer to Mr. Whitmore.

It is, of course, just there that the enormous savings are effected by the introduction of electricity.

Messrs. Fraser and Chalmers' guarantee, given by Mr. Mountain as 40 lbs. of steam during one wind of 60 seconds, may be quite correct,

Mr. Hooghwinkel.

but spread over a whole day this may be from 50 to 100 lbs. These test figures, supplied by the makers, and on which Mr. Mountain bases his estimates, are therefore wholly deceptive. The steam consumption must be taken over twenty-four hours, or, better still, over a year.

It is well known that a steam winding engine can accelerate the load in no time, yet this is done at enormous losses, which is exactly the point where the electric winder scores, performing this duty smoothly and economically.

The overwinding and safety appliances which make use of electricity as the governing agent are far simpler and easier to adapt than the mechanical appliances on steam winders. The question of safety and simplicity of all electrical appliances, not only winding, has been discussed since over twenty years, and the very existence of power supply stations, electric railways and tramways ought to be a sufficient answer.

One point also in connection with the safety ought to be put forward, however: the ammeter or wattmeter enables the mine-owner to know exactly what he is doing, and where or by whom his money is wasted, the state of haulage roads and of the shaft, girders, etc. This knowledge, unobtainable in steam practice, makes both for economy and safety.

My position has been from the beginning not to question the correctness of Mr. Mountain's and Mr. Whitmore's figures, as far as they were actual figures; others have done so with remarkable results, especially as regards the only actual figures of electric winding given, namely, at the Grand Hornu Colliery. I am, however, not in agreement with the makers as regards the economy of this winding engine, even in this case, where two or three engines are running from the same power station. It may, or it may not, be possible to compensate for the enormous starting losses and resulting unequal load on the generating station to a certain extent by the judicious running of the three winders. The figure of 1·46 units (varying between 1·78 and 1·40 units) per H.P.-hour as given by the makers, seems to me too favourable in comparison with the figure of 1·44 and 1·50 obtained with balanced winders. This is certainly the case when only one winder is considered, and at the present discussion this was the case.

Leaving alone for the present the question of capital expenditure, a balanced system has in all cases been proved to be far more economical than a simple 3-phase winder, or, to make the comparison more general, for all such intermittent work as rolling mills, winding and traction.

Every one who has followed the current and voltage variations at the Preussen winding engine will readily agree.

Besides, the batteries in traction stations and the balancers and flywheels (fixed on the mill shafts) in the first rolling mill installations all point in this direction. Moreover the makers of the Grand Hornu and Preussen winding engines are now almost entirely making the Ilgner balancing system, as may be seen from their latest printed matter. Although I do not consider the Ilgner system as finality in winding,

it is at present, if intelligently adapted to each individual plant and local requirements, the only economical system of electric winding. There are, however, many variations and simplifications, which will reduce the first costs considerably. I am looking forward, however, in not too long a time, to a simple and purely 3-phase system of balancing. Mr. Hooghwinkel.

The actual figures obtained at the Zollern Colliery are at present the only reliable source of information, and I am therefore quite willing to accept Mr. Mountain's revised figures given in Table VI., remarking, however—

(1) That the wages are British wages taken from Mr. Mountain's Table III., for an identical case with steam, while maintaining at the same time that these wages can be reduced by having stokers, ashmen, etc., combined in one power station.

(2) That the depreciation and interest throughout my paper are calculated as in his own, on a basis of 10 per cent. over 250 days.

This table should then read as follows, after substituting the figures for steam consumption during actual winding.

	Coal Wound per Day.	Depth in Yards.	Hours Winding.	Cost per 100 Tons.	Do. with Interest and Depreciation.	Value Coal.	Steam per H.P.-hr.
				s. d.	s. d.	s. d.	
Mr. Mountain's estimate, Elect. ...	1,500	500	{16 / 8}	2 7	{6 11¾ / 11 3}	3 6	37½
Average for 12 steam Colls. as given by Mr. Mountain ...	1.700	430	11	5 10	9 8¾	4 3	90
Mr. Hooghwinkel's actual costs at Zollern	1,350	{330 / 550}	{16 / 8}	1 5¾	{6 1¾ / 9 9¾}	3 6	26 01

This table, giving Mr. Mountain's own figures and mine as corrected by him, shows the remarkable saving in costs of winding only, mainly due to the last column, while the resulting saving when taking capital cost into account largely depends on the hours of winding.

The actual figures obtained at Zollern without interest and depreciation are nearly half those estimated by Mr. Mountain, and very much less than with steam. The average figure obtained with steam winding from Mr. Mountain's list is merely shown up as an illustration of what is done at present with steam, and showing what can be done by electricity, but it is clear that every case has to be considered on its own merits.

The principal points at issue between Mr. Mountain and myself are :—

(1) That I maintain that the only safe basis of comparison is the amount of steam or coal consumed per useful H.P.-hour.

Mr. Hooghwinkel.

(2) That the cost of electric winding should be calculated from the cost per unit in the common generating station, and no allowance made for special separate generating plant or part of it for winding purposes.

(3) The same as far as interest and depreciation of plant is concerned.

(4) The steam consumptions obtained with electric winding are far below those estimated by Mr. Mountain, and the savings therefore greater. The maximum speed with electricity may be much less than at present usual with steam winding, while at the same time the average speed of getting out the coal remains the same, and I do not think that Mr. Mountain has succeeded in proving these points to be incorrect.

Proceedings of the Four Hundred and Thirty-ninth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 29, 1906—Mr. JOHN GAVEY, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on March 22, 1906, were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associates to that of Associate Members—
John Walker Fyfe.

From the class of Students to that of Associate Members—
Hugh William Geare.

Messrs. D. H. Kennedy and H. G. Solomon were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Walter Day Conning.
George Cox.
William Tuxford Evans.
William Graham Griffith.
William Alexander Jackson.
Horace John Jones.
Frank Westlake Parkinson.
Wilfrid Skaife.
Harry Webber.

As Students.

Ernest Adams.
Robert Allen.
William Thomson Bottomley.
John Stanley Brooker.
John Darke.
Edward Mitchell Elborne.
Harold Lester Robert Groom.
Harold McCullough.
John Mactaggart.
Walter Freemantle Scott.

Donations to the *Library* were announced as having been received since the last meeting from The Board of Education, Messrs. A. Constable & Co., The Engineering Standards' Committee, H. R. Kempe, T. C. Martin, R. H. Smith, H. G. Solomon, The Victorian Institute of Surveyors, Whittaker & Co. ; to the *Building Fund* from Mr. J. Gavey, C.B., and to the *Benevolent Fund* from The Executive Committee of the Electrical Exhibition, 1905, Messrs. J. Gavey, C.B., S. G. C. Russell, and R. J. Wallis-Jones.

The PRESIDENT : You will have noticed that, among the contributions to the *Benevolent Fund*, a donation has been received from the Executive Committee of the Electrical Exhibition. As most of the members know, the Exhibition was a great success financially, and the Executive Committee, having realised a surplus, devoted considerable sums to very useful purposes, and amongst others they have given £350 to the *Benevolent Fund* of the Institution.

The thanks of the meeting were then accorded to the various donors.

The PRESIDENT : Before we proceed to the formal business of the meeting, I have to make a brief announcement. It will be a very long time before the members of this Institution forget the Presidency of Mr. R. K. Gray. The almost regal manner in which he entertained the members of the International Congress, and the members of this Institution in the name of the Institution itself, but at his own cost; the manner in which he carried out the work of Secretary as well as President in the interregnum between the death of the previous Secretary and the appointment of the new one, and the manner in which he represented this Institution at St. Louis, are all engraved on our memories. As the members are aware, it was determined by the Institution to recognise his services in some small degree by presenting him with his portrait in oils, and it is proposed to make that presentation at the next meeting. It is to be hoped that the Institution will be very largely represented when that presentation takes place.

The discussion on Mr. Sparks's, Mr. Mountain's, and Mr. Hooghwinkel's papers was continued (see page 522).

The meeting adjourned at 9.30 p.m.

Proceedings of the Four Hundred and Fortieth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 5, 1906—Mr. JOHN GAVEY, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on March 29, 1906, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members—

John W. Black.
James Herbert Garratt.

From the class of Associates to that of Associate Members—

Edwin Henry Dixon.
George Hardwick Hardwick.
Charles A. Pulsford.
John W. Record.

Messrs. L. Gaster and S. A. Simon were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Thomas Baxendale.
Samuel Fildes.
Charles Follenfant.
Percy Brailsford Lawson.
George Duthie Leys.
William Henry Upton Marshall.
Frank Howard Michell.
Eustace Ridley.
George Young.

As Associate.

Charles Anthony.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. H. M. Hobart, H. F. Parshall; to the *Building Fund* from Messrs. S. Paterson, J. Shaw; and to the *Benevolent Fund* from Messrs. A. H. Bate, S. Paterson, to whom the thanks of the meeting were duly accorded.

Presentation to Mr. R. Kaye Gray.

The President: Gentlemen, we now approach one of the interesting events of the evening to which I referred at the close of our last meeting. As then announced, it is proposed to make the formal presentation of one of the two portraits you see hanging on the wall to our Past President, Mr. Gray. Sir Joseph Swan, the Chairman of the Committee which organised the presentation, has been kind enough to undertake to propose the resolution.

Sir Joseph Swan: Mr. President, I shall have to ask your permission to say a few introductory words before I come to the ceremonial part of the proceedings. It will be in the recollection of all the members, except those very recently elected, that Mr. Gray's tenure of the Presidency was marked by several exceptional features. His term of office was exceptionally long, and necessitated an unusual amount of labour, and that was very much added to by the lamented death of the Secretary, Mr. McMillan, which threw upon the shoulders of the President at that time a large amount of extra work. But I think we will all agree that the circumstance which especially marked Mr. Gray's Presidency was the meeting in London of the International Congress of Telegraph Engineers. That meeting brought to London a large number of our continental *confrères*, and the onus of their entertainment and of the ladies who accompanied them fell on Institutions like our own, and on a few of the principal firms and persons connected with the telegraph industry. The larger share of the duty of hospitality and entertainment fell to the lot of Mr. Gray, and you will agree with me that the manner in which he discharged the exacting duty which was laid upon him was in every way admirable. Everything that could be done to contribute to the pleasure of the visitors was done munificently. The entertainments were of a princely character; the members of the Institution largely participated in them, and their splendour was reflected upon the Institution itself. Thence arose a general desire among the members to commemorate that event, and to express in some durable form appreciation of the exceptional service of the President. With that object, a Committee of the members of the Institution was formed, Mr. Patchell being chosen Secretary. The outcome of their deliberations was an urgent request to Mr. Gray to allow a memorial portrait of himself to be painted—a not particularly modest request, perhaps, on the part of those who were already so deeply in his debt. However, they counted rightly on Mr. Gray's unfailing kindness, and induced him to give the necessary time to carry out the idea. Then the happy thought occurred to the Committee of connecting the artistic execution of the work with a name held in high

honour among telegraph engineers—the name, I mean, of Sir Charles Bright, through his daughter, Miss Beatrice Bright, whose excellent portrait of Sir William Preece most of us are familiar with, and which was a sufficient guarantee of her skill as an artist. With these few words of prelude, it now only remains for me, speaking on behalf of the subscribers and of the Institution generally, to ask you, Mr. Gray, to be good enough to accept one of these portraits, and our best thanks for enabling us, by additional sittings, to obtain an excellent replica for the Institution. Looking back once more to the time of the Congress, I am reminded of the gracious support given you by Miss Gray, on several occasions when the assistance of a lady was almost indispensable. If I may without too great incongruity do so, I would ask you, in connection with the reception of this memorial of a historic event, with some of the incidents of which Miss Gray was associated, to convey to her our too tardy but very heartfelt thanks.

Mr. R. K. Gray: Mr. President, Sir Joseph Swan, ladies and gentlemen, I hardly know what to say in return for your great kindness. It is a very proud moment in my life to know that those among whom I have worked for some time should wish my portrait to hang on the walls of the Institution. Sir Joseph Swan has been exceedingly kind in what he has said, and I wish to thank him for coming here to-night to make the presentation. I have no words at command which will adequately express my feelings, but I would like to say that it gave me very great satisfaction to know that the work of painting the portrait had been entrusted to Miss Beatrice Bright, the daughter of my old friend, the late Sir Charles Bright. I had the pleasure of serving under Miss Bright's father for a considerable time at the beginning of my career, and there was no kinder man than he. I do not desire to encroach further upon your time, because to-night is, after all, a business meeting; I can only once more say that I am greatly indebted to your Committee and to you all for your extreme kindness to me, and greatly appreciate it.

The President: Before we proceed with the business of the meeting, I think the members present would like to express their thanks to the Committee who have carried out the work of organisation in connection with this presentation. When the formal event takes place, one is sometimes a little apt to forget the amount of work involved in the preliminary arrangements. This Committee has worked most diligently for us, and I am sure you will say with most satisfactory results. I should therefore like to suggest that we pass a vote of thanks to the Chairman, Sir Joseph Swan, to the members of the Committee, and last, but not least, to the energetic Honorary Secretary, Mr. Patchell, who has borne the heat and burden of the day.

The resolution was put and carried with acclamation.

Sir Joseph Swan: I cannot let the vote of thanks pass without an acknowledgment, but I must transfer by far the larger share of it to Mr. Patchell, for he has done by far the largest part of the work. It is to him that we are chiefly indebted for its successful termination. I therefore accept the vote of thanks on behalf of the Committee, and

thank you very much, but I again say that the vote of thanks is chiefly due to Mr. Patchell.

Mr. PATCHELL: Mr. President and gentlemen, Sir Joseph's thanks alone are an honour. But I cannot let this incident pass without thanking you very heartily for the way you have appreciated my efforts in this matter. It has truly been a labour of love; if we had more such labours of love, life would be sweeter. Working for a man like our former President is always the greatest pleasure. When I found to-night that I had collected Sir Joseph, Mr. Gray, and the artist in the room, I thought I had earned my Easter holiday. There is only one person I have really envied in this matter, and that has been the artist, who has been thrown more into Mr. Gray's company, through the painting of the portrait, than any of us.

The discussion on Mr. Sparks's, Mr. Mountain's and Mr. Hooghwinkel's papers was concluded (see page 538).

The meeting adjourned at 9.30 p.m.

NEWCASTLE LOCAL SECTION.

A REVERSIBLE BOOSTER AND ITS RUNNING.

By C. TURNBULL, Associate Member.

(*Abstract of Paper read January* 15, 1906.)

The following paper refers chiefly to the Lancashire Reversible Booster, but it is the hope of the author that some of the remarks may be generally useful. The paper is divided into sections, which deal with (1) The Use of Batteries with Boosters; (2) The Duties of Boosters, and Methods of Meeting Them; (3) Description of the Lancashire Booster; (4) The Constant Load Problem; (5) The Working of the Booster.

1. THE USE OF BATTERIES WITH BOOSTERS.—Load factor is always poor on a traction system with few cars, especially if the district is hilly. It is true that our journals occasionally show load factors of 30 per cent. and even 40 per cent. for stations of this kind, but this is due to their method of calculating the load factor by taking the maximum load on the traction system at the time when the highest combined load is on the station. The highest combined load may occur at a time when the traction load is below normal, and load factors calculated on this basis are misleading. Furthermore, high loads may occur on traction at any time, and it is necessary to keep plant always running to deal with them, whereas with lighting the loads can be reckoned on and the plant run at an economical load. Hence it comes about that while the traction load factor is better on paper, it gives a much worse running-plant-load-factor than lighting. Electric railways have this difficulty in an aggravated degree. There are but few trains in use, and the starting currents are immense and liable to overlap. This entails a large excess of plant both in generating and sub-stations, and mains have to be excessive in size. It is likely that batteries will prove a most important factor in future railway work. This will be the more recognised should it be found possible to improve batteries so that their one-minute rate can be made immensely more than their one-hour rate. Certain factories which have excessive loads for a short time, such as for cranes, dock pumping, and the like, also find batteries with boosters of the utmost service. Batteries can only be used under such circumstances with boosters, automatic or otherwise. Regulating cells are out of the question for sudden demands, and in any case

boosters must always be used for charging batteries, so that they might as well be used for discharging them also.

2. THE DUTIES OF A BOOSTER.—For a traction load at 550 volts, 260 cells will be found a convenient number. The cells will vary from 1·8 to 2·5 volts per cell in ordinary working, giving 468 to 650 volts across the ends of the battery. This is a fall of 82 and a rise of 100 volts from the bus-bar pressure, and the first function of the booster is to compensate for the rise and fall. The second function of the booster is to cause the battery to discharge when the load increases beyond the capacity of the generator, and to charge up the battery again with the surplus, as soon as the outside load falls below the capacity of the generator.

The first and obvious method of doing this was to use automatic rheostats to control the booster fields. These rheostats were actuated by the varying volts on the generator, which had to be shunt wound so as to vary its volts with the load. Generally speaking, such gear was not well suited to the sudden changes of traction work. There was too much lag in the chain of apparatus, and it has not come into general use.

Feeder-current boosters have been used to some extent. With these the feeder current flows through a coil on the booster magnets, working in opposition to a shunt coil. When the feeder current exceeds a certain amount it overpowers the shunt coil and causes the booster to discharge the battery, and *vice versâ*. The defect of this system is that it does not compensate for the state of the battery. When the battery is fresh it is apt to take the load off the generator, while a run-down battery responds but sluggishly.

Compensating boosters have been developed. The booster in this case is arranged to compensate for the variation of the battery volts so as to fulfil the equation—

$$(\text{Battery} + \text{Booster})\ \text{Volts} = \text{Constant}.$$

It was hoped that such a combination would work in parallel with a shunt-wound generator in somewhat the same manner that a compound generator would work in parallel with a shunt generator. The (battery + booster) was to take up all the variations, giving a steady load to the shunt generator. When an increased load came on the line there would be a slight increase of load on the generator, which would drop its volts a little. This would cause the (battery + booster) to discharge. When the load went off the line, the shunt generator load would lose some load, and its volts would rise slightly, so causing the (battery + booster) to charge to such an extent as to keep the load steady on the generator. The idea seemed good, but in this case the (battery + booster) volts did not keep quite steady, and the combination lacked stability. There was too much for the booster to do. It had to compensate for some 200 volts variation on the battery side and to respond to some 5 volts change on the generator side. Its working was obviously affected by the state of the engine governor, by

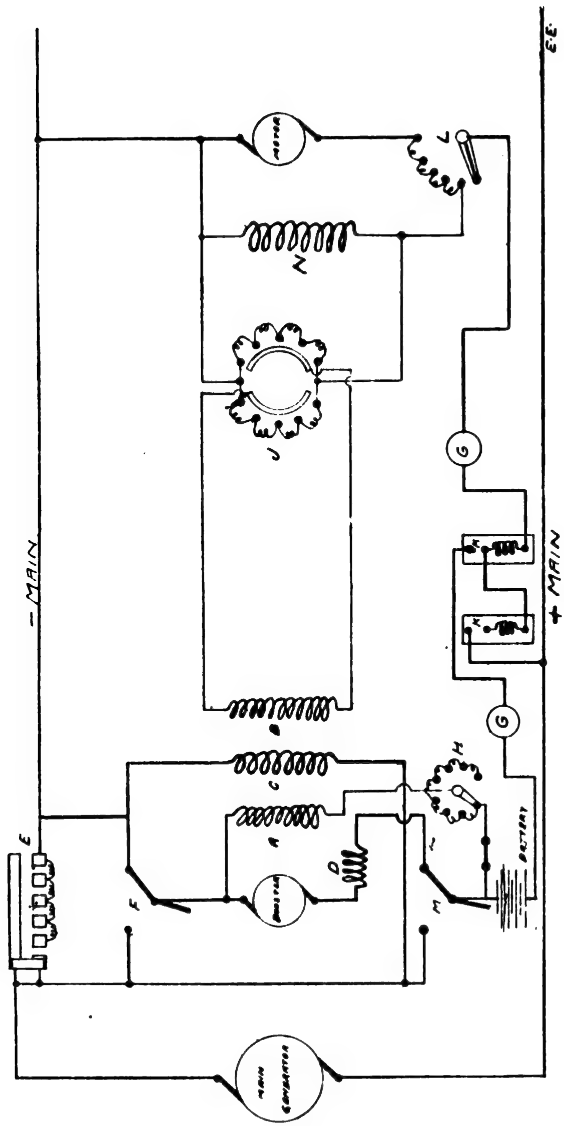
E.E.
MOTOR
L
N
J
G
+ MAIN
— MAIN
H
C
A
D
BOOSTER
F
M
BATTERY
E
MAIN GENERATOR

FIG. I.

the dynamo characteristic, and by a host of other things. Also any alteration of the bus-bar volts threw the whole thing out of gear.

3. THE LANCASHIRE BOOSTER.—This was developed to meet the conditions of actual working. It consists of a booster driven by a

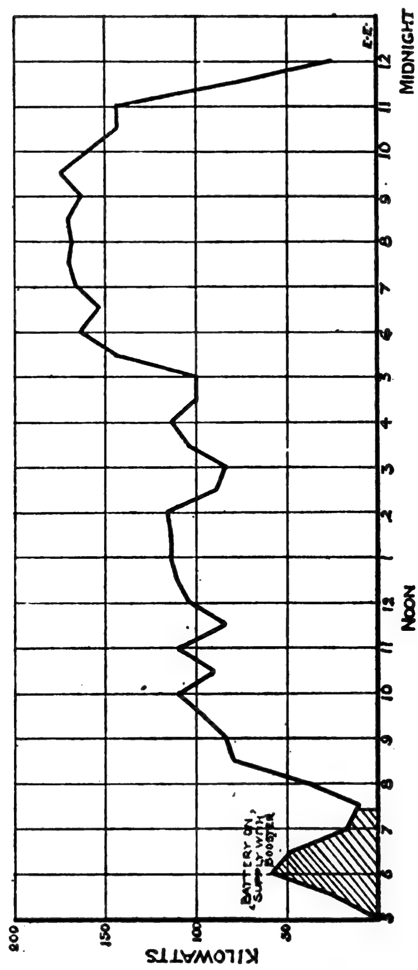

FIG. 2.

motor, and its windings are as shown by Fig. 1. There are four coils on its magnets, A, B, C, and D. The first coil, A, is connected right across the booster brushes. It is therefore energised by the difference of potential between the battery and bus-bars. Should the battery give 500 volts and the bus-bars 550 volts, then there will be 50 volts on the terminals of the A coil. The booster is so designed that this will cause the booster to give just 50 volts in favour of the battery. If the

battery be at 600 volts and the bus-bars at 550 volts, then the booster will give 50 volts against the battery. Hence in every case the combination fulfils the equation—

$$\text{(Battery + Booster) Volts} = \text{Bus-bar Volts.}$$

Under this system only, the combination is unstable. The battery might either charge or discharge according to chance. A small governing force, however, will control it perfectly.

The governing force is given by the operation of Coils B and C. Coil B is a shunt across the bus-bars and takes the 550 volts. Coil C carries the main generator current and acts in opposition to B. The action is as follows:—

When the line load increases, there is first of all a slight increase in the generator current. This strengthens up the action of Coil C, so causing the booster to discharge the battery. The battery thereupon begins to drop its volts, but this has no effect, as the alteration of battery volts is compensated for by the A coil. So long, then, as the line demand is more than the amount of output that the generator has been set for, the battery will continue to discharge to the extent required. When the line load decreases, there will be first of all a slight decrease of load on the generator, which will cause the C coil to weaken. When the C coil falls in strength below the B coil, the effect will be to cause the booster to charge the battery. The battery will, however, only be charged to such an extent as to keep the normal load on the generator. Any tendency to an excessive battery charge would strengthen up the action of the C coil, and this would check such overcharging effectually. The action of the booster, therefore, is to keep the load steady on the machine within narrow limits, as is well shown in Fig. 3, between the hours of one o'clock and midnight. The state of the battery has no effect on the working, which is just as good whether the battery be charged right up or partially run down. D is a series coil to compensate for booster armature reaction and drop, and it assists the sensitiveness of the booster's working. The booster magnets are laminated, which enables it to respond promptly to rushes of current.

Regulating resistances, as will be seen from the figure, are fitted which enable the action of the booster to be controlled to suit the particular loads which may happen to come on at any time.

Combinations of Booster and Battery.—The booster and battery may be worked in the following ways:—(1) Booster and battery on bus-bars with generator, keeping the generator load steady within narrow limits. This is the normal method. (2) Booster and battery on bus-bars with generator, but with coils regulated to make its action comparatively weak. This method is useful when the load on the line is small, with occasional jumps. Under these conditions the (battery + booster) meets all the peaks, but maintains a benevolent neutrality during the times when the load is small, when it is not desirable for the battery to charge because it is already full. (3) The battery may be floated on the line without the booster. This method is occasionally suitable

when the line load is slack. (4) The booster may be set to mainly charge or mainly discharge the battery, as may be desired; this by regulating Coils B and C. Under this state of matters it will still respond properly to any excessive outside load. (5) The battery and booster can be put on the bars alone without a generator. The bus-bar volts can then be regulated by adjusting the strength of Coil B by hand. (6) The battery and booster can be put on the bus-bars with the booster arranged to compound up when the load comes on. (7) The battery can be put on the bus-bars without the booster. All the above combinations are needed to enable the utmost to be obtained in actual working, and the arrangement of switches on the board permits of the easiest possible working.

4. The Constant Load Problem.—As will be noted, the booster gives a load on the generator steady within certain limits. These limits may be made narrow by strengthening the coils. Actually, absolutely constant load is like an absolutely level railway—it costs more to obtain than it is worth. A railway engineer would never propose to make a perfectly level line through a hilly country, and an electrical engineer will not find it pay him to endeavour to get the booster to make an absolutely straight line across his peaky traction load curve. In both cases it pays to follow the peaks and valleys by more or less gentle undulations. This point is so often overlooked that you may pardon me for labouring it. If the maximum load were twice the average load, and if the load were fairly even all the day long, then we would be able to deal with the conditions by having the generator equal to the battery and the combination equal to the maximum load. Unfortunately, things are not this way in practice. Traction load has its peaks and valleys as surely as lighting load. Fig. 2 shows a particular case. (To construct it, the wattmeter was read every half-hour, and the average load deduced from the readings. Thus 50 units in half an hour gives an average load of 100 k.w.) The average load is only from a third to a quarter of the maximum, while the output per hour varies greatly during the day; also another day would give quite a different curve. With constant load, and a battery equal to the generator in output, we must either fail to meet the peaks, or else we must seriously overcharge the battery by running the generator at a sufficient load to enable it to meet the peaks, so putting out more current in an hour than the line takes. Constant load on the generator can be met by having a battery very much larger than the generator. Thus a 33 per cent. load factor with constant load requires a battery twice as big as the generator. This would be a good solution if the load were known and steady from day to day. Actually the load varies from day to day and from season to season. Besides, the battery is seldom large enough.

In short, a careful examination of the problem will show that for practical working absolutely constant load on the generator is not suitable. The best result from the generator and battery is obtained by arranging for a small rise of load on the generator when the line load rises, and for a small drop of load on the generator when the line

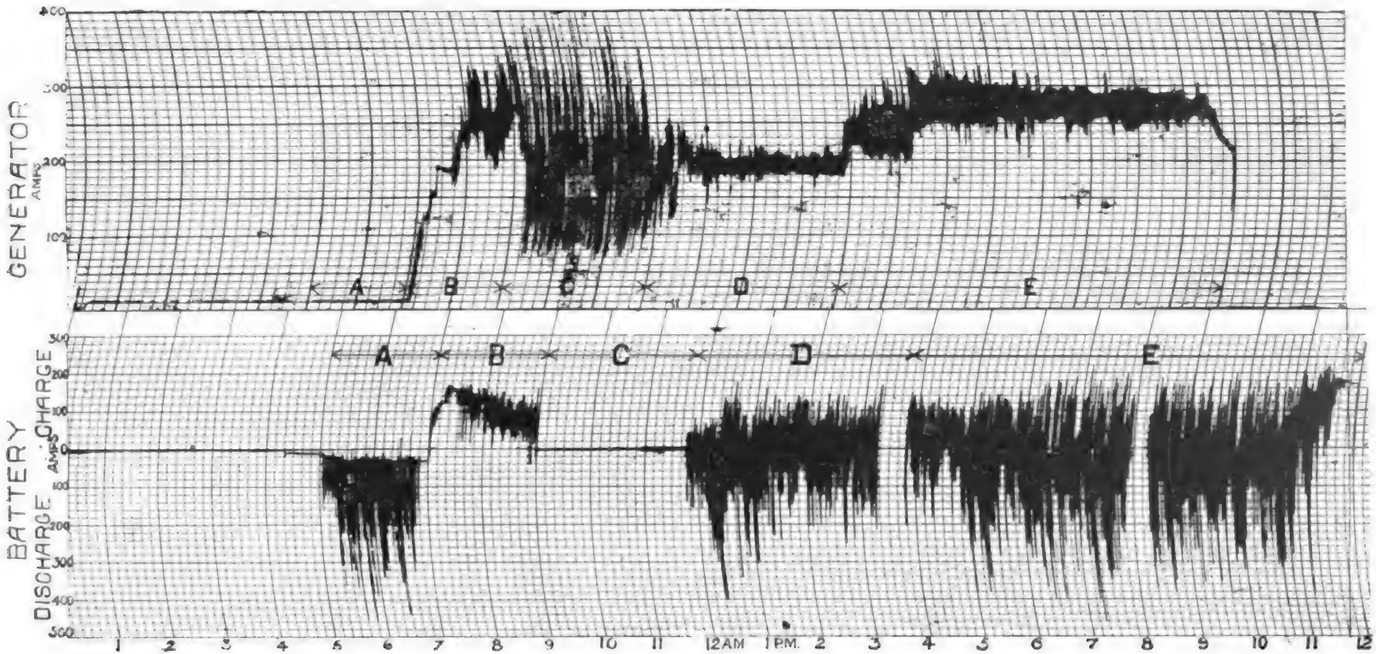

FIG. 3.—Showing Generator Amperes and Battery Charge and Discharge.

load goes down. This enables the battery to be charged at a lower rate than the discharge rate, as is necessary for good working. The addition of means whereby the battery can be set to respond to heavy overloads only during a slack time is vitally necessary to the good working of the battery, for any attempt to obtain constant load during a quiet period will inevitably result in serious overcharging of the battery. During such slack periods the average demand on the line is less than the average output on the machine, and with constant load the difference will overcharge the battery. This can best be got over by arranging the booster coils so that their action can be weakened by resistances and shunts during such light-load periods, so that the booster does not give enough volts to overcharge the battery. Seeing that the load is not heavy, the battery will not run down much, and hence the weakened power of the booster will enable it to discharge the battery quite well to meet any momentary heavy demands. During such working the main generator load will rise and fall to meet the outside load. Any heavy rush of current on the line will cause the booster to discharge the battery enough to meet the demand.

As will be seen from Fig. 1, the Lancashire booster is arranged on those lines. The shunt coils have resistances in series with them, and the main current carrying Coil C has an adjustable diverter, E, in parallel with it. By this means the booster can be adjusted to meet the requirements of the moment. Fig. 3 shows the actual working. From 5 to 7 in the morning the battery and booster alone took the load. From 7 to 9 the generator was running and chiefly charging the battery, this being a slack time. Until 12.30 the generator took the load by itself. After 12.30 to midnight the generator was assisted by the battery and booster. As will be seen, from 12.30 to 4 the load on the generator was only about 200 amperes, and the battery took the rest. After 4 o'clock the generator load was increased to between 250 and 300 amperes, while the battery rushes went to over 400 amperes.

5. The Working of the Booster.—The actual voltage on the bus-bars has no effect, and the bus-bar volts can be adjusted at will. The generators can be compound or shunt wound as desired. Reverse-current breakers are not needed even with compound-wound generators, because the current cannot come back on the generators. As will be seen, the C coil would lose all of its power when the generator load fell to nothing, and this would cause the booster to boost 100 or more volts against the battery. This effectually prevents current from coming back on to the generators. [Should any current come back it would cause the booster to boost still more vigorously against it.] Similarly, the action of the coils prevents the generator from taking load off the battery. There is no tendency for the battery to shirk its work, as the operating forces are strong enough to make the battery do its duty as long as its volts are within working limits. The booster is extraordinarily stable in its action, and has no tendency to hunt. Indeed, it is more simple to run a battery and booster in parallel than to run two generators. The steadiness of the load on the main generator makes it run well and without sparking, while the volts across the booster brushes are low enough to prevent any difficulty there.

Paralleling.—Should the battery breaker come out, the paralleling is as follows:—(1) Cut out A coil; (2) adjust B coil regulator until paralleling voltmeter is somewhere near to zero; (3) slam in breaker; (4) run back regulators to position—time, about four seconds. The voltmeter switch may be left permanently on the paralleling stop. The usual regulator wheels on the switchboard may be replaced by straight handles with great advantage, as these can be operated more rapidly.

Circuit Breakers.—There has been a difficulty with booster breakers, because the booster may run to destruction if the motor breaker comes out and leaves the booster breaker in. Breakers have, therefore, generally been interlocked, so that the booster breaker is thrown out by a relay if the motor breaker happens to come out. The arrangement shown in Fig. 4 used with the Lancashire booster overcomes the

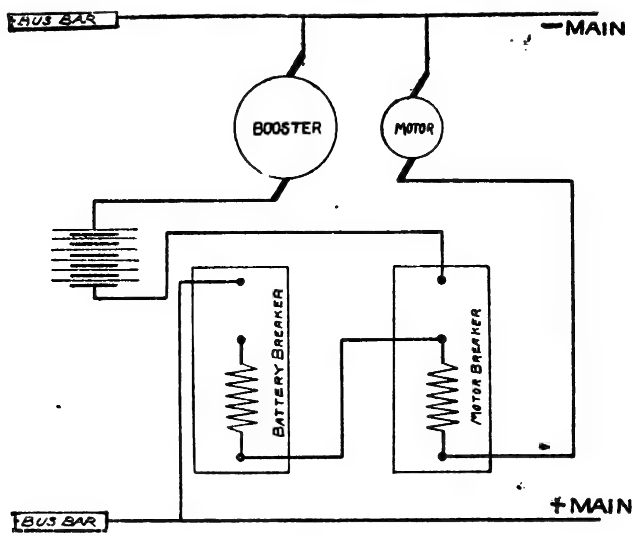

FIG. 4.

difficulty. The battery current, as will be seen, goes through the contacts of the two breakers in series, but it only goes through the *solenoid* of the *battery* breaker. An excess current on the battery, which is the usual thing, blows the battery breaker, but leaves the motor running on the battery. An excess current on the motor, which is quite a rare thing, also cuts off the battery, but leaves the motor running on the bus-bars. Thus paralleling is quite easy after a breaker comes out, seeing that it is not necessary to restart the motor. Whichever breaker comes out, the motor is still left with a breaker to protect it, so that it would be cut out in the event of a short occurring in the motor itself. Breakers should be of the loose-handle type. A good time limit on the breakers would also be an improvement, allowing the feeder breakers to come out rather than the generator breakers. When the motor is run

on the battery without a generator to take small loads, this arrangement of breakers is convenient, as it is only necessary to put the breaker in when it comes out, seeing that the motor remains running on the battery when the breaker opens.

Three-Wire Booster.—The Lancashire booster can be made to work on the three wires, but there is the objection that it sometimes happens that one side is permanently out of balance, and hence one side may become overdischarged or overcharged if cafe be not taken. In certain cases I think it better to put the battery on the outers only, and to use a balancer.

Size of Generators.—It is still the almost universal custom to put in three generators of equal size when a station starts. This a relic of the days when armatures usually ran about red-hot at full load, and when it was the custom for every dynamo to have its spare armature to deal with bursts, which occurred as regularly as the changing seasons. That day has gone, and the practice might well go with it. The first three generators of a station should be properly graded in size. The small loads could then be dealt with by the baby set, and as the loads increased there would always be a set ready to run them economically. At the present time a large number of stations are running two equal-sized sets for a load which is just too big for one set, with disastrous results to the cost-sheet. With graded sets, when the station grows up, the generators work in for years to come, for almost all stations can do with one small set of, say, 100 k.w. to run on one or two lighting feeders which need a special pressure, and the sets above this in size would also come in. The engineer whose sets are properly graded is in a happy position, for he can always pick out a generator which will just suit his conditions.

Non-Condensing Generators.—While every one recognises that condensing stations are better for economy than non-condensing, it has not yet been fully explained why many of our non-condensing stations get better coal-consumption than condensing. Take, for instance—

	Coal.	Works.	Total.
Govan	0·21d. ...	0·71d. ...	1·08d.
Edinburgh	0·28d. ...	0·58d. ...	0·92d.
Darlington	0·34d. ...	0·71d. ...	0·98d.

My impression is that non-condensing engines do well where it is possible to arrange them to run at about full load, and probably this would be found to be the case in the above stations. In many cases it may pay to put a battery and reversible booster into non-condensing stations where circumstances do not allow of condensing arrangements being added conveniently. The experiment of graded plant run non-condensing with battery and booster may well be tried with small new traction stations, as it would save the capital cost of the condensing arrangements, while the condensers could be added afterwards if desired.

A motor generator may be used conveniently as a link between the traction and lighting boards. This will enable a small load on the

lighting board to be taken from the traction board, so saving the running of a special set. For night load the traction battery may be put right on to the lighting board through the booster, which may be hand-regulated to give the right volts. Where such a link is used in the daytime, it is desirable to have the breakers on the main generator and booster with a time limit. If the feeder breakers be then free acting there will be but little chance of the main supply coming off, seeing that a feeder fault will clear itself without cutting off the main supply.

Number of Cells.—This should be chosen so that the booster has the minimum amount of work to do to get the greatest efficiency. For 550 volts, installations have had as little as 240 cells, but 260 will be found more suitable where heavy work is to be done. If the cells discharge to 1·8 volts on a heavy load they will need a boost of about 80 volts with this number.

Size of Battery.—This is a subject which needs considerable care in its consideration. If the generating plant be already installed, then evidently the battery may be chosen of such a size that it may enable the generator to meet the peaks. There is a tendency to put in very small batteries, but this is not always good policy. With a 33 per cent. load factor theory would demand that the maximum output of the battery should be twice that of the generator. While this gives a larger battery than many engineers think well to put in, still the result is good. As will be seen in Fig. 3, the battery there meets peaks nearly twice as great as the generator load, and this gives excellent working. As a practical rule, for new plants I would suggest that the hour rate of the battery should be equal to the full-load rate of the generator, and the two together must be able to meet the peaks. The circuit-breaker on the battery should be set as high as can be arranged for with the battery-maker, certainly not less than 50 per cent. over the hour rate, to meet exceptional peaks.

The number of units generated by the dynamo must be equal to the number of units sent out on to the line plus the loss in the battery and booster. There is no difficulty in arranging this in actual practice, seeing that the dynamo can be run just sufficient hours to put out the required units. On a heavy day it is run a little later, or started up sooner, as may be required. The regulating resistances on the booster can be altered as required during the day, so that the battery may be not overcharged or overdischarged at any period of the day as the load varies.

The cell-boxes may be made larger than is necessary to accommodate the number of plates in use. This is of utility in several ways. Thus a cell can be inspected by putting an L-shaped inspection lamp down, and turning it round so as to shine up from the bottom of the box. This method of inspecting is most satisfactory. If it is desired to increase the size of the battery more plates can be added. This should be done by taking old plates out of some of the cells and filling up others. The depleted cells can be fitted with entirely new plates.

The actual work done by cells when working with a reversible

booster is very little. While the curve of discharge and charge looks formidable, it is yet of a frothy nature, and integrating meters on the charge and discharge will show comparatively little work even on a heavy day. The cells should, therefore, be specified to work at heavy rates of charge and discharge with durability. Efficiency is of less importance than durability. Actually cells working under these conditions are extraordinarily efficient, and no doubt makers will find it possible to improve and cheapen cells to meet this kind of load, as the demand increases.

Acid tends to sink to the bottom of large cells in spite of gassing. It is quite easy to get the gravity of acid at the bottom of a cell by sucking some up into a vessel and testing it there. Where there is room a large tube may be put down to the bottom of the cell, its top being covered over tightly by the hand, covered with a rubber glove. When the tube has reached the bottom, if the hand be taken off the top the acid will rush in from the bottom of the cell. This can then be tested by a hydrometer in the ordinary way. If the acid be found to be too dense at the bottom, it can be stirred up by a wooden plunger. When this is forced down in the side space it will force the acid up from the bottom of the cell to the top, and so mix it up properly.

The question of water for topping up is most important, and should be settled before the contract is placed. Otherwise, the engineer may find that he has no suitable water to fill the cells up with, and this will place him in a most awkward position. Condensed water from the boilers is not suitable, as it may contain iron and other deleterious matters. Lead worms in stills are unsuitable, as the soft water dissolves the lead, and this damages the cells. Suitable stills may be had, and battery-makers are gradually wakening up to the fact that the water question is of sufficient importance to require careful handling. If a still is required, it should be fixed up before the cells are erected.

Working the Battery.—It is evident that the ordinary battery-makers' rules cannot be complied with in the case of traction batteries. The discharge and charge are mixed up, and the conditions are quite different from lighting battery practice. A very practicable method of working is as follows:—

When the generator is started up in the morning there is usually a slack time, so that it can be arranged that the battery is chiefly charging. The battery attendant should go round the cells now and see that the cells all gas up together. He can top up at the same time and carry out the ordinary work on the cells. When the cells are full up the charge and discharge meters should be read. By this means the readings will show exactly the proportion of input to output each day. If the readings are taken each day at a particular hour this will not be the case, as the readings will vary with the state of the battery, and will not be of much use. When the charge is completed a little current may be run off the cells by adjusting the booster regulators, and this will insure that there is no overcharging of the cells. For the rest of the day the booster may be regulated to give charge and discharge about equal.

The battery-room should not be too well lighted by windows, as too much light makes it difficult to inspect the cells. The wiring may be done on insulators. At intervals lamps may be hung on long flexes of Lyric 3/25 wires. These are useful for looking into the cells from above. Acid-resisting paint is liable to chip off from a ceiling, and I have found that good enamel is better, covered with acid-resisting varnish. Ventilators should be arranged to keep flies and dust from getting in. It is desirable that the room should be electrically lighted from the positive side of a 3-wire system, for if lighted from the negative side there may be over 700 volts difference between the lamps and the cells, which may be undesirable to the battery attendant.

A grating made of wood dipped in melted pitch is satisfactory for the attendant to stand upon in examining the cells.

It has been proposed to clean out a battery in the following manner:—A tube is put to the bottom of the cell, and its other end is connected to a barrel. The top of the barrel is then connected to the condenser, thus creating a vacuum in it. The effect of the vacuum is that the acid and sediment rush into the barrel. It is stated that this is an effectual method of cleaning.

The switchboard shown in Fig. 5 has worked very well. The breakers are on the live side, but practically everything else is on the earth side. Wattmeters may be used for registering the charge and discharge, the shunts being taken off the bus-bars, so that the meters virtually become ampere-hour meters. The meters must be arranged so as not to go backwards. There should not be too many recorders, as these are expensive to keep up. Usually an ampere recorder is fitted to show the battery charge and discharge. This should have the same shunt as the ammeter, as there is no need to have two shunts. Probably, however, a battery recording voltmeter might be of more use, as the battery is usually doing all right if its volts keep within limits.

DISCUSSION.

Mr. Lunn. Mr. J. R. P. LUNN: I have made a few notes in connection with a reversible booster at Darlington, where I have found that it is more economical to run the battery without the booster as much as possible. At first, we ran the booster all day; after a time we only used it between 5 p.m. and 11 p.m., and at the present time we only use it about six hours a week in order to give the battery its weekly overcharge. We find that by allowing the battery to "float" on the bus-bars, it gets charged quite sufficiently for ordinary purposes. We supply a tramway load which varies regularly from a very small amount to 250 kilowatts, by means of a 100-kilowatt generator and a battery, and we find that the load on the generator averages about 85 per cent. of full load and never gets more than a few per cent. above full load, and the voltage does not vary more than 4 per cent. each way. With reference to the suggestion that regulating resistances should be fixed on the switchboard, I consider that resistances should be kept away from the switchboard as far as possible. It is almost as easy to fix

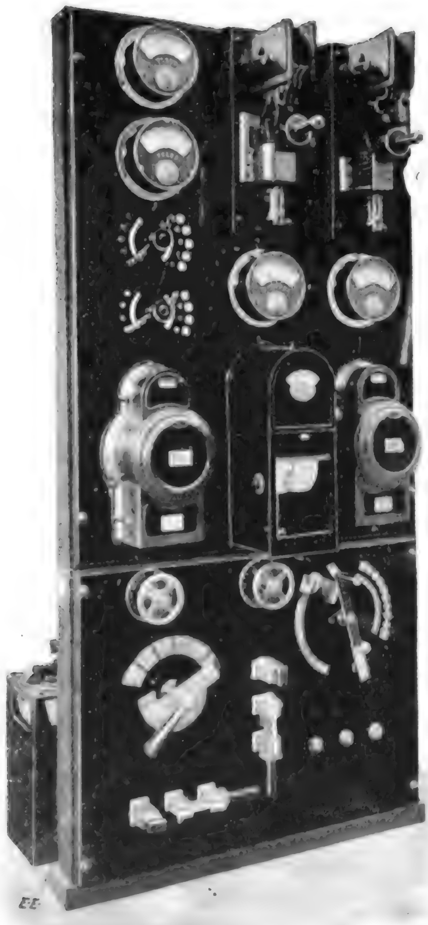

FIG. 5.

them under the switchboard and operate them by means of a hand wheel. As a rule there is quite enough on a switchboard without adding bulky things like regulating resistances. With regard to the mention that has been made of the comparatively low coal consumption at Darlington, I do not think that this is due to the absence of condensing plant, as is suggested by the author (the amount of steam used per unit being rather high), but to economies effected in the boiler house. With regard to battery maintenance agreements the simplest way to get over the objectionable clauses put into maintenance agreements by some battery-makers is to draw up your own maintenance agreement and ask the battery manufacturers to quote rates for maintaining the battery in accordance with that agreement. Mr. Lunn.

Mr. F. C. KIDMAN: With regard to Mr. Turnbull's remarks on the link between "traction" and "lighting" plant, I have had experience of running a balancer off the traction bus-bars with rather poor results. This balancer in question consisted of three machines on a rigid shaft, and was really used as a twin generator, the motor being driven off the traction bus-bars. It was only used in this way on very light loads on Sunday mornings, but the variation in the traction bus-bar voltage varied the speed of the balancer motor so much, and, in consequence, the supply voltage, that the method was abandoned for a battery. Mr. Kidman.

Mr. DAVIS: Does Mr. Turnbull think it worth while having the field laminated? Mr. Davis.

Mr. H. L. RISELEY: I would like some information as to overload, as Mr. Turnbull's generators do not appear to do more than about 20 per cent. I think that, at any rate for a few minutes, they might be run at a great deal more than this. With regard to the question of "non-condensing" stations running at so low a cost, the reason why some "condensing" stations do so badly is that they have to pump their water so far; in one case I know of the distance is about three-quarters of a mile, which, of course, is a very expensive business for the station. Mr. Riseley.

Dr. W. M. THORNTON (Chairman): As far as rapid response to sudden loads is necessary, the solid magnets are better than the laminated, as the core currents prevent the change of the magnetisation and so reduce the momentary back electromotive force of the magnetising circuit. The cores may be made laminated to prevent loss of efficiency by eddy currents. Dr. Thornton.

Mr. TURNBULL (*in reply*): The booster at Darlington is of the "Crompton," not of the "Lancashire" type. The results obtained at Darlington are due to the fact that their battery is not usually called on to discharge at much over one-third of its one-hour rate. For any fairly heavy rush of current they drop to about 480 volts. In ordinary stations people want to use their battery with momentary discharges up to much in excess of the one-hour rate, and they wish to keep the bus-bar volts right also. The "Lancashire" board is arranged to allow the battery to be put right on to the bars, without the booster, during very slack times. Replying to Mr. Kidman, I would point out that the voltage is kept exceedingly good when the Lancashire booster is running, so that it is possible to get a good pressure on the lighting side with a link Mr. Turnbull.

Mr. Turnbull.

between the lighting and traction sides. In reply to Mr. Davis, the "Lancashire" fields are laminated, as only thus can the machine respond to the rushes of current which come on. In reply to Mr. Riseley, on pure throttled governed engines there is no real overload, except by passing high-pressure steam into the lower pressure cylinders. The latter method, however, is not of much use in actual practice, as it is very extravagant in steam and bad for the engine. Replying to Dr. Thornton, I would point out that his remarks seem to cover the case of a fixed voltage applied to a solenoid, whereas here, the coils are in series with 550 volts, and there is practically no choking back. Lamination is necessary under these circumstances for quick response and absence of heating.

BIRMINGHAM LOCAL SECTION.

A NEW METHOD OF AUTOMATIC BOOSTING.

By MAX J. E. TILNEY, Associate Member.

(*Abstract of Paper read January* 17, 1906.)

The system of automatic booster regulation that I am proposing to describe differs from the more generally known methods inasmuch as the regulating coils have not got to be wound on to the booster itself, but are wound on to the carcase of a very small motor, quite independent of the main machine, which can therefore be less costly in design.

The system is one of automatic regulation on the shunt field, and this regulation is automatic both when the booster is charging and discharging, the apparatus being so arranged as to provide for reversal of the shunt excitation.

It is not of much importance whether the polepieces are laminated or solid, though a booster with laminated poles naturally gives rather better results, due to the flux following variations of shunt current more rapidly; it is, however, sufficiently rapid with unlaminated poles for a regulation within 4 per cent. to be obtained on a system with a maximum load of 1,200 amperes at 430 volts with a variation of 500 amperes representing a change from 400 amperes discharge to 100 amperes charge.

I propose to deal to-night only with the apparatus as applied to boosters and batteries, but there is no reason why the simple non-reversing regulator should not be used for controlling generators working without a battery on a varying load.

The standard apparatus is shown in Fig. 1, and Fig. 2 is a complete diagram of the arrangement showing booster and battery, but I wish again to emphasise the point that it is only the regulator that has to be added to any existing station having shunt-wound booster and battery, to obtain this automatic regulation.

The standard arrangement for tramway systems consists of a multiple way regulating and reversing switch, as shown in Fig. 3, mounted on a kind of table having all the resistances fixed underneath it.

The switch contact blocks are directly connected to the spindle of

a small motor armature. There are two pairs, one pair making contact on rings 1 and 2, and the other pair on rings 3 and 4 in Fig. 3, each pair being connected.

Fig. 3A shows details of switch-gear on a larger scale.

The reversal of the booster excitation and the discharge before reversal is effected by the two contacts marked S S in Fig. 3, the switches as they pass on to and over these contacts short-circuiting the booster field windings. This will be easily followed out on the

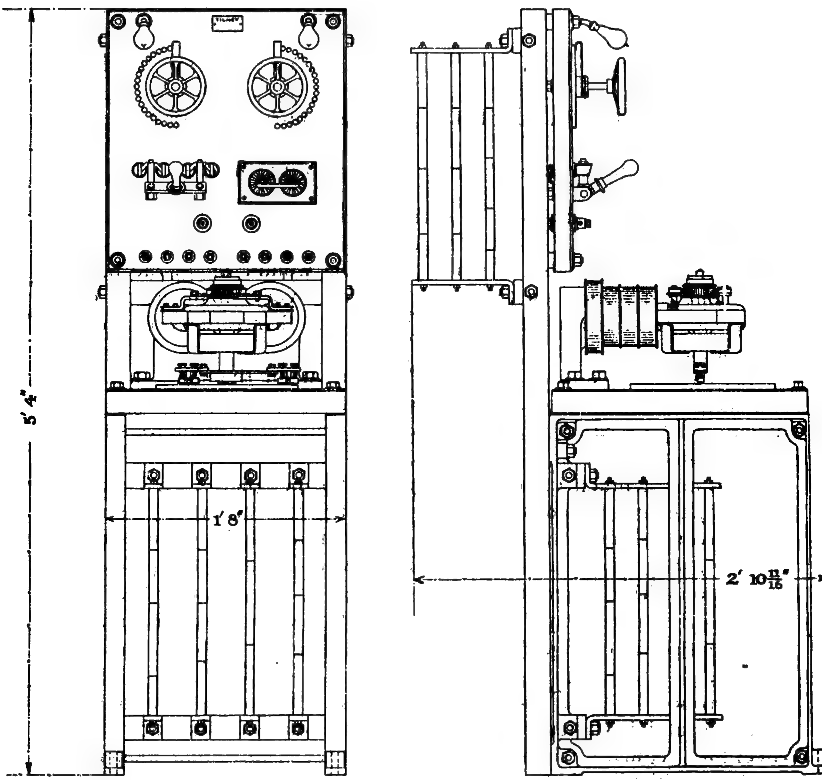

FIG. 1.

diagram. In practice, no sign of any inductive spark is visible, even with very rapid reversal.

As the full boost is never required on discharge, there is a permanent resistance, as shown in the diagram, in series with the regulating resistance on the discharge side.

The armature has a small current always passing through it, and the polepieces are wound with four coils, numbered 1, 2, 3A, and 3B, as shown on diagram, Fig. 2.

Above and behind this table are mounted the terminals for the four field coils and the armature, two small S.P. switches and two small regulating switches with their resistances behind them, also in the standard arrangement two lampholders wired in series with the little

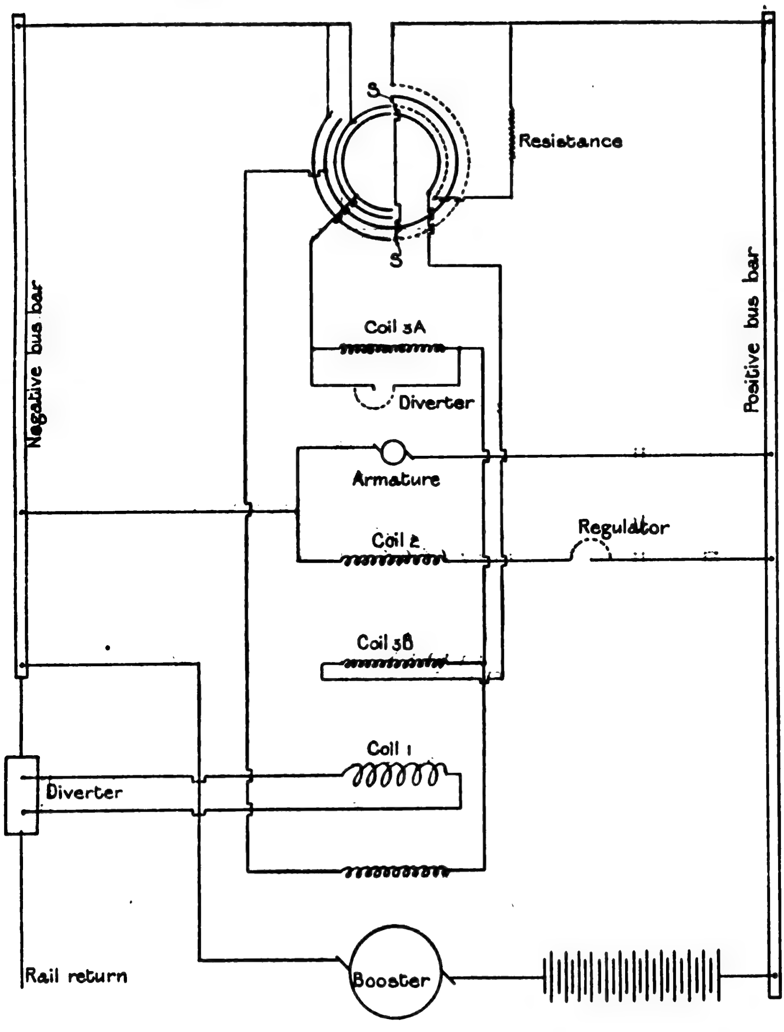

FIG. 2.

motor armature so that this circuit can be put across the bus-bar voltage while using a low resistance armature, this is simply to save the expense of winding such a small armature for the high voltage.

One of the two S.P. switches is for this armature circuit, and the

other for the circuit of the No. 2 Coil, which also has one of the regulators in series with it.

The other regulator is a diverter for No. 3A Coil.

In the case of an old booster system being converted, the existing field breaking switch or switches can be used; but if the apparatus is being provided for a new station, these switches would be mounted on the front of the table.

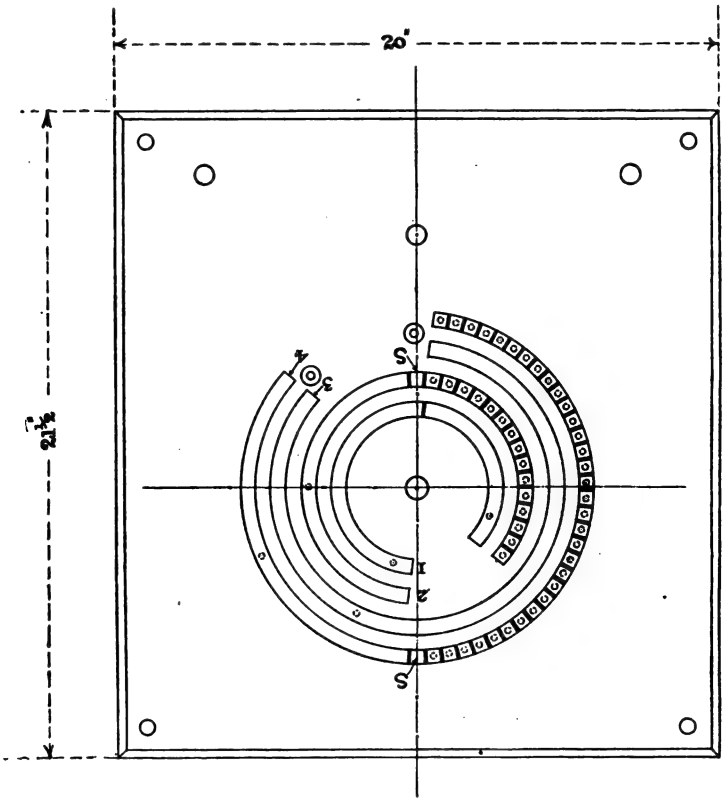

Fig. 3.

The only other piece of apparatus is a main diverter capable of carrying the full output of the station, and this is in a form similar to the shunt of a moving coil ammeter of large capacity, but of slightly higher resistance.

It will be seen that the armature *never makes a complete revolution*, and is therefore quite unlike the motor armature on a Thury regulator, which is always revolving.

The field coils are in four different circuits :—

No. 1 carries a definite proportion of the outside load diverted through it by the main diverter.

No. 2 is set to give a certain number of ampere turns depending on the output of the machines running in the station, and this value of No. 2 Coil only has to be altered when a machine is shut down or put on the bus-bars.

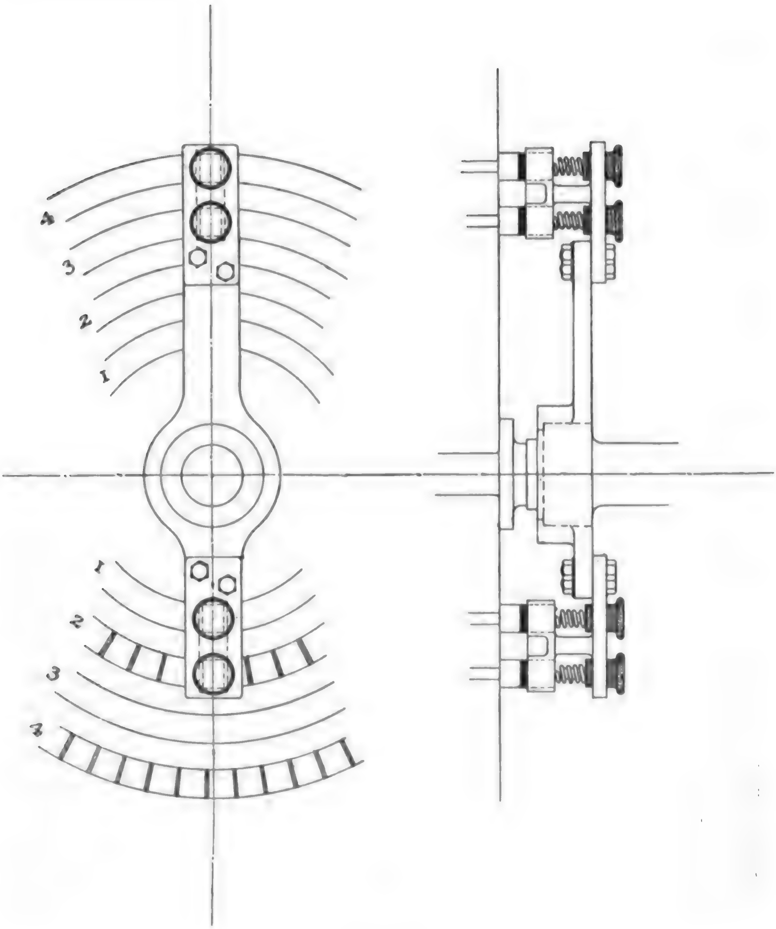

FIG. 3A.

Coil 3A is in the circuit of the booster field when the latter is charging the battery, and Coil 3B when it is discharging; the change from one to the other being effected by dividing the inside ring of the switch at the point where the booster field is short-circuited before reversal.

Coil 3A has connected in parallel with it the small diverter mentioned above and shown in the diagram.

This is to compensate for the rise in volts of battery.

In practice, I find that except when the cells have been considerably run down, or when it is desired to give them a gassing charge, this diverter has not to be touched.

I would point out that this diverter will, for practically any booster, never have to be of larger current capacity than, say, 5 amperes, and this takes the place of the costly, and, as I find, sometimes dangerous diverters necessary in the case of many automatic boosters, where the main current of the station has to be carried by a variable resistance, whose value may have to be altered with considerable amounts of current passing.

The whole apparatus can be made up in standard form, and only requires the main diverter and the regulating resistances arranging for each case; the size of the main diverter, of course, being dependent on the station output, and the resistances depending on the magnetisation curve of the booster.

I find, in practice, that it is well to give a regulation of four volts per step on the charge side, and three volts on the discharge side; and it is very advisable to work out the resistances on each side carefully.

The motor armature is designed to carry about 0·5 ampere, and its best figure is somewhere in the neighbourhood of 0·3 ampere.

No. 1 Coil on the field is arranged to carry 50 amperes as a maximum, at the maximum output of the station, and it has 40 turns, so its maximum value is 2,000 ampere turns.

Coil 2 has 1,000 turns, and a current capacity of 2 amperes.

The current in this coil is varied by means of the regulator mentioned previously, and its ampere turns value can be varied from 100 up to 2,000 in the 20 steps provided.

These two coils will be the same whether the station in question has a top load of 100 amperes or 5,000; in the former case half the load would be diverted through No. 1 Coil, and if the generator output was 50 amperes, the value of Coil No. 2 corresponding to it would be 1,000 ampere turns; and in the second case only $\frac{1}{100}$ of the output goes through No. 1 Coil, and the value of Coil No. 2 corresponding to a generator output of, say, 4,000 amperes would be 1,600 A.T.

Coil 3A has 1,000 turns and a current capacity of 2·5 amperes, though this may be altered later if it is found that it is necessary; but I believe diversion would be necessary to correct for rise in cell volts before that value is reached, except in the case, perhaps, of a very large booster.

Coil 3B has 2,000 turns and a current capacity of 2 amperes, as I believe it will be found that, except as before in the case of a very large booster, all the volts required for boosting out will be obtained with lower values of shunt current than this, as the boost-out will not exceed 70 volts within the limits allowed by battery companies, assuming the usual 240 cells on a 500-volt traction system.

The operation of the apparatus is really very simple, and depends

on the fact that any movement of the switch not only alters the booster field, but also alters the value of Coils 3A or 3B, always tending to produce a resultant zero flux in the small motor-field system.

Coils 1 and 2 are always producing a magnetising effect in opposition to one another.

Coil 3A acts in the same sense as Coil 1, and therefore the switch tends "on charge" to set itself in such a position, that the flux due to Coils 1 and 3A is equal to the flux due to Coil 2.

On discharge, Coil 3B comes into action (Coil 3A is out of circuit), and Coil 3B acts in the same sense as Coil 2, and the switch tends to set itself so that the flux due to Coils 2 and 3B is equal to that due to Coil 1.

Take an example:—

Assume a maximum possible output of a station 2,000 amperes, and that there are two machines, one 800 amperes and one 400 amperes, the battery being capable of dealing with a discharge of 800 amperes at the one-hour rate, and a maximum of 400 amperes on charge.

Let us assume that the 800-ampere machine is running with the battery. The diverter will be sending $\frac{1}{40}$ of the main load through No. 1 Coil. No. 2 Coil would be set at 800 ampere turns representing the generator output.

If the load on the feeders is 800 amperes, it will be clear that Coils 1 and 2 will be exactly balanced, and the switch will be in the neutral position, the booster field will be unexcited, and the battery will be floating at about 2·1 volts per cell.

If the cells should be rather low, say at the beginning of a day's work when they have had some load taken out at night after the plant was shut down, it *may* be necessary to set Coil 2 a bit below the generator capacity, but this will only have to be done for a very short time, and I have found the apparatus work well with balanced load when the cells were reading anywhere between 1·95 and 2·2.

If the cells are high the diverter on Coil 3A will have been in use, and the booster will be slightly opposing the cells, as the balance will extend over several steps of the resistance, on the charge side, away from the neutral point.

I should say here that the switch operates with a difference of about 50–0–50 ampere turns, that is, that the limits of variation in the load, on such a system as our example, without the switch moving, would be 100 amperes, being 50 ampere turns on either side of the absolute zero field on the small motor, and a battery of the size taken would deal with such a variation with a drop in volts certainly not exceeding 2 per cent., and probably not exceeding 1 per cent.

Now returning to our example:—

Let us assume that an additional load comes on, say 300 amperes.

Coil 1 rises in value to 1,100 A.T., being 300 A.T. in excess of Coil 2, and the motor now has a strong field, turning the armature and switch round towards the discharge side. Coil 3B comes into operation and adds the necessary 300 A.T. in the same sense as Coil 2.

With our standard winding of 2,000 turns, this means 0·15 ampere,

and with the booster the author has in his mind this will mean about 30 volts boost.

Of course for boosters with very different magnetisation curves it may be necessary to alter the turns on both Coils 3A and 3B, but from particulars I have obtained of a large number of boosters I do not think any alteration in the number of turns is likely to be required, but if it is, it will be in the direction of using fewer turns, which will therefore not necessitate any alteration to the rest of the apparatus.

In most tramway stations the peaks are of short duration, and I do not anticipate any trouble from the use of the diverter in No. 3A Coil, because, assuming the battery to be charging and the cells to be at about 2·5 volts, if a discharge, even at a high rate, is taken for a short time, as soon as this goes off, the cells will very quickly rise to their previous figure.

If in our example the load, after rising to 1,100 amperes, now goes back to 400 amperes, Coil 1 will have a value 400 A.T., and Coil 2 and Coil 3B will greatly overpower it, and the switch will move round towards the charge side until the value of Coil 3A is 400 A.T., so that Coils 1 + 3A = Coil 2.

In our case, with Coil 3A undiverted, this would be with a shunt-current of 0·4 ampere, giving 55 volts boost; but of course, if the cells are well up, the diverter will have been in circuit and the boost will amount to whatever value is necessary to charge at 400 amperes.

If it is desired to use the battery and booster without any generating plant running, it will be quite clear that, if the S.P. switch controlling No. 2 Coil is opened, Coils 1 and 3B will try and balance each other and the boost-out will depend directly on the outside load, any variation making a corresponding variation in the resistance in the booster shunt field, and also in the ampere turns due to Coil 3B.

It will be easily seen that the size of the station makes no difference whatever, as the percentage of load variation at which the regulator begins to operate is the same in all cases, so that in a small plant with what I may call lower electrical elasticity, the small variations which then amount to 1 per cent. of maximum load, will be dealt with as smoothly as the 1 per cent. variations in load of a 5,000-k.w. station.

I find that with solid cast steel poles on the booster the switch generally rather overshoots its mark, and then comes back. This is particularly the case with large variations in load, but is an advantage as it helps to make the excitation follow the shunt current a trifle quicker than it will do with the switch going direct to its proper position.

To overcompound so as to compensate for drop in feeders it is only necessary for the value of Coil 2 to be set a little below the capacity of the plant running, and to divert Coil 3A by a slightly lower resistance.

It will be easily seen that this will, when the booster is charging the battery, still allow it to charge up to its full capacity, or the full capacity of the plant, and when discharging will allow the regulating switch to go a little further round on the boosting-out side, which will raise the volts of the battery and booster in series somewhat higher than is

necessary to take its fair proportion of load. This, of course, tends to rob the plant of just so much load as will allow the machine volts to rise to an equal amount and I have been able successfully to raise the volts on a small system to 520 when the load comes on, and reduce them to 500 when it comes off, so that the cars have been able to keep

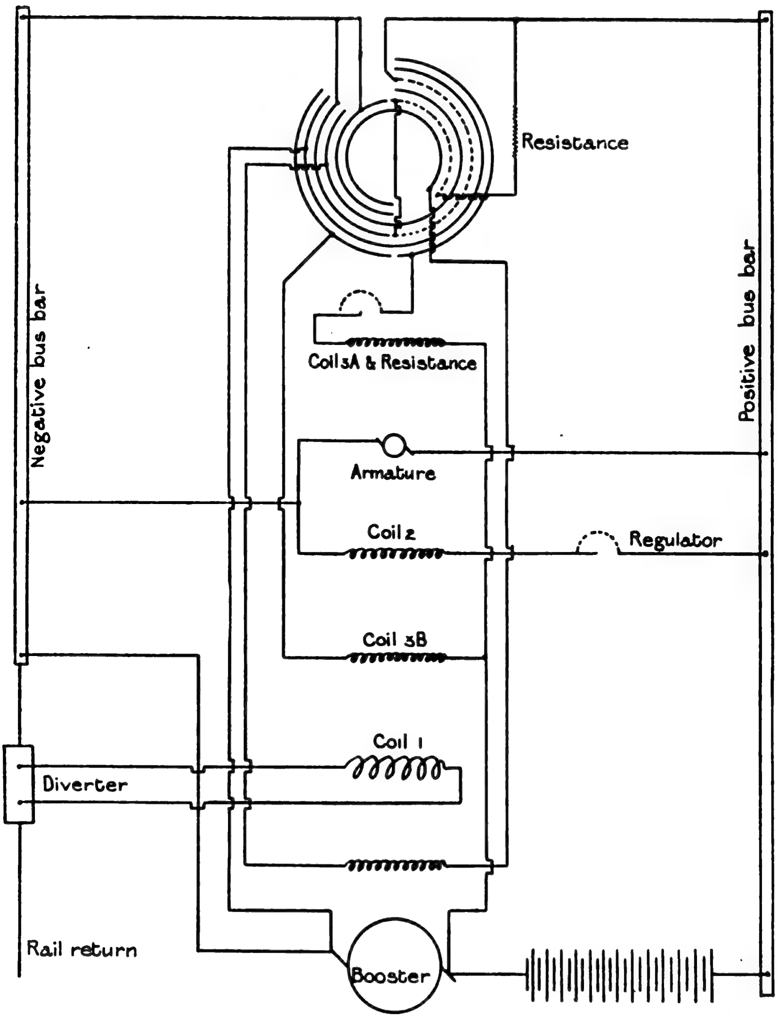

FIG. 4.

better time at the busy part of the day than they had previously been able to do.

In using this apparatus we meet the same point as in all other systems, namely, that if the maximum capacity of the plant running

approximates to the maximum charging rate of the battery, better regulation is obtained than is obtainable if the plant capacity much exceeds the battery capacity.

The next point to consider is the question of efficiency and general running losses.

These latter may be put down as consisting of :—

(1) Current in small motor armature.
(2) Current in No. 2 Coil.
(3) Volt drop on main diverter and No. 1 Coil.
(4) Copper loss No. 3A and 3B Coils.

Of these, No. 4 may be ignored; the resistance of No. 3A is about 5 ohms, and of 3B about 12 ohms. In the latter case it is only 12 ohms moved from the permanent resistance into the coil, and in the former it is only probably half of the rise in the resistance due to the warming up of the machine shunt windings.

Loss No. 3 is also quite small, as the resistance of the main diverter is, for a 2,000 ampere station, only about 0·00015 ohm, the series coil resistance being about 0·009 ohm, so that at top load the loss would only be 1,000 watts.

Loss No. 2 would at full load in our case be $1·2 \times 500 = 600$ watts, and loss No. 1 would be $0·3 \times 500 = 150$ watts, making a total *at maximum load* of 1,750 watts.

A very fair average load factor for a tramway station is 25 per cent., so that the average losses per hour due to the regulator would be, say, 1 unit. The efficiency of the arrangement may therefore be considered as the efficiency of the booster and its motor.

I do not claim for this arrangement the very high efficiency claimed for the Highfield booster, but I am of opinion that too much can be paid, in first cost, for a small gain in efficiency, particularly when it means putting out of service plant which is already installed.

In Fig. 4, another method of arranging the apparatus is shown, but though interesting, the author is of opinion that it would not work well unless the booster polepieces were very carefully laminated, as the 3A and 3B Coils depend on the variations of the booster terminal volts and there is a much greater lag in the terminal volts than there is in the exciting current, which would almost certainly produce hunting of the switch, and there is the additional disadvantage of having another circuit added to those already on the apparatus, and another added loss.

A view of the whole apparatus is given in Fig. 5. The first of these has been set to work regularly at the Tramway Station of the Urban Electric Supply Company, Glossop, the particulars of which may be of interest :—

A 4-pole booster, with laminated polepieces, is in use. This machine was originally fitted with series coils, but they have now been cut out and it is working as a simple shunt-wound booster. The maximum load on the system is about 400 amperes, and the pressure required on the trolley line is a full 500 volts. The station has a 45-k.w. set,

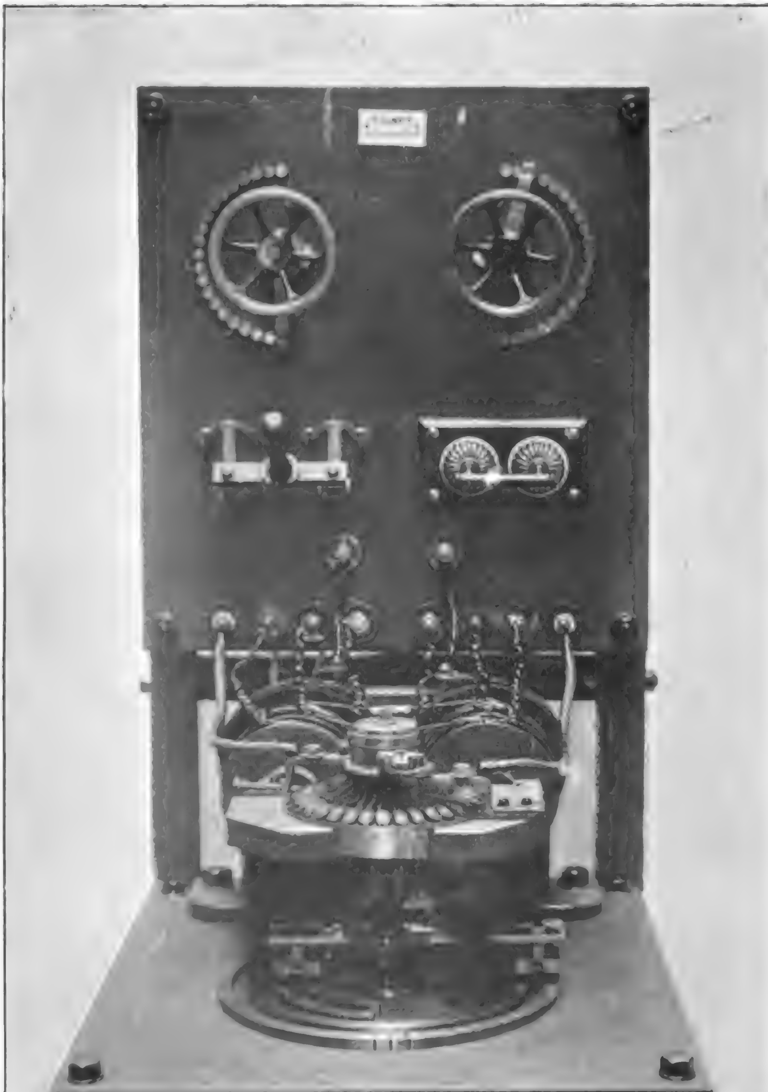

FIG. 5.

which was installed with the intention that it should deal with this load in connection with the battery capable of discharging up to 350 amperes; but it was previously found necessary to use a 90-k.w. set on the heavy load, in order to keep the volts up to anything like 500 when the peaks came on. By using a regulator they are now able to do the heaviest load with the small set, and at the same time they are able to get the battery so well up that at 11.30 p.m., when the cars come in, there is no necessity to run on for charging purposes, except one night a week, when they give the battery an hour's gassing charge.

The practice at this station is to arrange for what I might call over-compounding, and to lower the volts when there is no load on the line to 500 in the station, and to raise them up to 520 or higher at the highest peaks. I, however, thought it would have been of interest if I could have obtained some figures to show how close it was possible to regulate, and some results have just come to hand which show that, while keeping the load on the machine about constant, it is possible to regulate from 65 amperes charge up to about 180 discharge, with an extreme variation of 16 volts; and I think that when the drivers get to know the apparatus a bit better they would be able to make it regulate closer than this.

The mere fact that this running of a 45-k.w. set in place of a 90 for the heavy loads gives the station more spare plant is satisfactory, and I have good hopes that the result of this will be that it will not be necessary to incur the additional capital expenditure which was in contemplation to meet next winter's lighting load.

Line Current in Amperes	0	30	40	50	70	90	100	120	130	160	190	210
Current into Battery ...	65	40	30	30								
Current out of Battery...					10	30	30	50	70	100	150	170
Line Volts	520	515	520	515	528	515	515	510	512	520	515	515

Line Amperes	0	20	30	50	70	80	100	150	200	250
Boost-in Amperes	120	100	65	60	30	20	0			
Boost-out Amperes								80	100	150
Line Volts	525	530	540	540	540	538	535	535	540	540

DISCUSSION.

Mr. J. S. HIGHFIELD (*communicated*): I should like to point out that my own boosters can be, and, in fact, are, used with any make of battery on an entirely uniform price basis. I think that Mr. Tilney will find that recent prices of my machines compare well with the prices of other types of boosters. In laying out a battery equipment to work on a variable load, the object in view being entirely, or partly, to damp out the variations in the load so that the generators run at approximately constant load, it is important that the battery should be of proper size for the work, whatever system of boosting or regulating may be used. It is not a fact that, as the concern grows, a larger battery is necessarily required. In these cases the conditions are different from those of a lighting load, where the battery should be properly increased as the Mr. Highfield.

Mr. Highfield.

load increases. In the cases of loads where an automatic booster or similar method of regulation is required, with reasonable care, the battery can be laid out so that it will be sufficient for years, since, as the load grows, in nearly every case its load factor improves. In some cases it is not economical to install a battery equipment to take entire charge of the variation; it is considered better to lay out the equipment so that part of the variation comes on to the generators. In all these cases it is merely a matter of a small degree of regulation, and in my particular design of booster just so much of the load is taken up as is desired. Mr. Tilney expresses some doubt as to whether the Thury system of regulation will be sufficiently quick to follow the variations in the load. When I first worked on the problem of regulating storage batteries, I had the idea that it would be necessary for the booster to operate as the load changes, but if a battery of a proper size is put in, this is not necessary. One has only to work a large battery in simple parallel, without any regulating gear whatever, with a shunt-wound generator, to find out that this is true so long as the battery is not too much charged. Of course, at the point where the pressure curve is rapidly rising much increased regulation is required.

Mr. McLeod.

Mr. R. S. McLeod (*communicated*): Mr. Tilney suggests altering old shunt-wound boosters and using them as automatic reversible boosters. In a few cases, perhaps, this might be possible, but there is no heavier work for a booster than a traction system, where the load varies from nothing to 100 per cent. overload continually, and this load has to be carried by the armature, sometimes with fairly large booster-field, and sometimes with no field at all. The commutating conditions are very difficult, and unless the machine has been specially designed for this class of work it is liable to give a great deal of trouble through sparking. Then, again, laminated fields are practically a necessity if one is going to follow up the peaks of a tramway load quickly enough. It may seem a small point whether the booster will respond in one second or ten, but any tramway engineer will know the enormous difference it would make with regard to keeping anything like constant load on his generators. I shall be glad to hear whether these boosters have been working for any considerable length of time, and if so, whether the freedom from sparking mentioned is maintained. It seems undesirable to put in an arrangement which necessitates regulating switches being continually moved over their contacts, when all necessary regulation can be obtained automatically by current and voltage variations in the system itself.

Mr. Siddeley.

Mr. H. Siddeley (*communicated*): Referring to Mr. Tilney's claim that his booster regulator is designed with a view to the use of existing boosters, I doubt if he will find the average booster suitable as an automatic reversible booster, on account of the usual design not being satisfactory from a commutation point of view, as when the full current is passing with no volts. Most boosters to be found in any power station with a battery would be of the non-reversing type, which would certainly be unsatisfactory as automatic boosters. In all other systems it is found in practice that a laminated field does make a great

Mr. Siddeley.

difference in the way the battery picks up the peaks, and I cannot see why this should be different with Mr. Tilney's method. Even if any one should be fortunate enough to find his existing booster suitable, it would be cheaper to rewind the fields after the method used by Turnbull and McLeod, and certainly simpler than introducing a new machine and automatic switchgear. I do not agree with Mr. Tilney that in practice his regulator with a solid field booster would pick up the peaks quickly enough, and think that if he attempted this with a compound machine the generators would certainly get most of the load. Probably Mr. Tilney has tried with a shunt-wound machine, and his arrangement would there be better, as any tendency on the part of the generator to take the overloads would result in a fall in volts, and, so to speak, meet the booster half-way in its regulation. It is also well known that the use of diverters in the main circuit makes the booster rather more sluggish than if the whole current passes through the series winding. In Mr. Tilney's method a very much larger proportion of the main current passes through the diverter than in other methods, and this would seem to tend to make this method more sluggish than the others, other things being equal. The volts varying in fixed steps of three or four would also not give a gradual enough regulation when the battery was fully charged, *i.e.*, very nearly approximating to the voltage of the line, and would result in either too heavy or too light charges and discharges, either of which would be against an even load being kept on the generator.

Mr. Bornand.

Mr. Victor Bornand: I am surprised at the title of Mr. Tilney's paper, as the principle described has been in use for several years in various tramway generating stations in this country. I refer to the system proposed and used by Mr. R. Thury, which consists of regulating the shunt of a booster by means of an automatically actuated rheostat. The $\frac{1}{10}$-H.P. pilot motor of the Thury regulator runs at from 2,000 to 2,500 r.p.m. Such speeds are largely used in fan motors and give no trouble. This speed results in a very quick motion of the gear actuating the field rheostat brush. It is such that with a shunt-wound booster and a sudden variation of load of 50 per cent., or a voltage drop or rise of, say, 25 per cent., only a few seconds are required to bring the voltage back to its normal value. Where sudden variations of load occur, as in a tramway system, a compound winding is used, insuring a still quicker regulation. The principal duty of the automatic regulator in such a case is to correct the action of the compounding. In the case of a lighting load it is usual to use a shunt winding only. Mr. Tilney is mistaken in stating that the Thury regulator never automatically reverses the shunt field. This is actually one of its principal duties. I cannot agree with the author's statement that the reluctance of the magnetic circuit of the booster generator is unimportant. In order to secure good results, attention should be directed to the shape and form of the armature tooth, and also to the way in which the wires are embedded on the slots. Mr. Tilney speaks of regulation within 4 per cent. I should like to know if this is 4 per cent. total or 4 per cent. each way. In either case it seems bad, as a steam engine governor

Mr. Bornand. will give better results. Under the conditions stated I consider that the Thury regulator will keep the voltage constant within half or even a quarter per cent. The author draws comparison between the armature of his motor and that of the motor of the Thury regulator. In the latter system the motor is not a necessity, as is the case in the former; in fact, the regulating gear can be driven from any convenient source, as, for example, the shaft of the booster. I do not see how the quickness of action which obtains in the Thury regulator (where the amount of iron is reduced to its lowest possible minimum) can be obtained in an electro-magnetic apparatus containing so much iron as that described in the paper. The author states that Coil No. 2 has to be set at a certain value, depending upon the number of machines running in the station; also the diverter of Coil 3A has to be altered when the cells are considerably run down. In my opinion an automatic reversible booster should need no hand regulation. I consider that the losses in Mr. Tilney's regulator are considerable. The small motor of the Thury regulator consumes only 90 watts at all loads. We are much indebted to Mr. Tilney for his attempt to improve a very interesting piece of apparatus.

Mr. Armistead. Mr. W. ARMISTEAD: I consider that Mr. Tilney's apparatus has several advantages. It gives satisfactory results when used with a simple shunt-wound booster. It is not necessary, as in other systems, to use a machine with under-saturated fields. It enables the battery to be charged at any rate. When switched in or out, the voltage across the apparatus is always that of the bus-bars. I consider that the author's system is a very neat method of dealing with a difficult problem.

Mr. Allingham. Mr. G. C. ALLINGHAM: In principle, Mr. Tilney's system is simply an ordinary differential booster worked through a relay, the differential coils being wound, not on the field of the booster itself, but on the field of a subsidiary motor. Thus, Coil 1 in Fig. 2 of the paper corresponds to the series coil, and Coil 2 to the shunt coil, of a differential booster, while Coils 3A and 3B correspond to the self-exciting coil which is connected across the brushes of the Turnbull and McLeod booster. The author's system has the advantages that the initial cost and the losses in the various coils are reduced, but I consider that these advantages are gained at the expense of the regulation. In every system there is a certain lag due to the time required to change the magnetisation of the booster field, but in the author's system we not only have this, but in addition a lag due to the motor field and to the time taken by the motor to move the lever of the field regulator. Again, a considerable change of current is required to overcome the friction of the apparatus before the regulator will operate at all, a disadvantage which is entirely absent from ordinary automatic boosters. The whole of the field system should be laminated, at least for traction work, as with solid fields the lag would be far too great. The author claims that he can compound to allow for a rise in pressure as the load comes on. Most automatic boosters have a compound winding which compensates for the drop in the battery, booster, etc., and this could easily be used

for over-compounding. Even if the main diverter is not to be used for regulation, I think it is advisable to make it adjustable, as it is impossible to fix its resistance beforehand, and it has to be adjusted on the job after starting up. I may point out that the cells should always be kept partially discharged while floating. If they are allowed to get too full, they will "gas" violently every time the load goes off and a charge goes into the battery. This frequent and violent "gassing" is very injurious to the cells, and causes excessive shedding of peroxide from the positive plates. The cells should only be brought up to "gassing" point once a day, and this is usually done just before shutting down at night. Mr. Allingham.

Dr. D. K. Morris: The principle of Mr. Tilney's regulator, namely that of regulation of the excitation of a shunt-wound booster, is the same as that of the Thury booster and regulator, and it is the rapidity of regulation attained which determines whether a booster of this type is suitable for dealing with a tramway load. For, during the small interval which must elapse between the coming on of a heavy load and the operation of the booster, the generator, even when not compounded, must take a large part of the sudden load, unless its characteristic drops much faster than that of the battery. Some figures relating to the reversible booster and regulator of the Thury pattern which has recently been installed in the Electrical Laboratory of the University of Birmingham may be of interest. The booster, which can deal with 300 amperes, has cast-steel poles, and an immediate change of voltage is therefore not possible even if the regulator could work at any required speed. It is found that when the booster's excitation has to be increased, the automatic regulator, which works at the rate of two notches per second, operates at one-third to one-half of the rate at which the booster can build up its voltage; but when the booster volts have to decrease, the regulator is well able to operate as fast as the booster voltage can follow. Under such conditions an automatic regulator more prompt in its action, such as that of Mr. Tilney, is not called for. No doubt, however, under average conditions, especially with a laminated field system, the quicker action of the new regulator will be of great advantage. Mr. Tilney claims as an advantage of his regulator that it can be compounded to give constant line-voltage, but there seems no reason why the Thury regulator should not be similarly compounded. Dr. Morris.

Mr. W. Fennell: Mr. Tilney refers to the efficiency of boosters. I wonder if we realise their inefficiency. I consider that the average efficiency of a booster is probably only about 50 per cent. It is important that the whole magnetic circuit of a booster should be laminated, the yoke as well as the polepieces. Many booster troubles are due to the motor, particularly to variations in the motor speed. The motor should consequently be looked to more frequently than is usually the case. I also think it important to mention that this system is not suitable for any works where a battery has to discharge unattended, as it does not correct for varying battery E.M.F. This makes it unsuitable for lighting works of small size where there is no one in attendance Mr. Fennell.

Mr. Fennell. from, say, midnight to 6 a.m., and during the day on Sundays, as the line volts will fall with the battery E.M.F. as it runs down.

Mr. Beyer. Mr. M. B. BEYER: The use of batteries in central stations has but recently come into vogue in this country, whereas they have been extensively used on the Continent for many years; in fact, a station without accumulators can hardly be found. Continental engineers do not favour the use of automatic and reversible boosters. I think that the boosting devices are as troublesome as the batteries themselves. They add to the initial cost and to the cost for attendance, money which would be more profitably spent in increasing the capacity of the battery. With a low capacity battery combined with a booster system, neither the machines nor the battery will be an economical success or enjoy long life.

Mr. Holden. Mr. S. H. HOLDEN: Mr. Tilney states that the loss in the regulator at full load is 1,750 watts, and at ¼ load 450 watts. But a large portion of the loss seems to be made up of fixed quantities, and I think that the loss at ¼ load will be about ½, rather than ¼, of the full load losses. The method of reducing the friction by making the polepieces of the small regulator motor embrace only the upper portion of the armature, thus causing the latter to float, is very interesting; I think, however, that the main frictional resistance will occur at the switch contacts. Has any wear been observed at these contacts?

Mr. Tilney. Mr. TILNEY (*in reply*): I am glad to be able to say that with regard to the friction question raised by Mr. Holden, the wear on the carbon brushes is inappreciable and the amount of sparking very small indeed. I am astonished at Mr. Beyer's statement that the use of batteries in central stations has only recently come into vogue in this country. There are, of course, many central stations supplying purely alternating current, but I should say that quite half the stations in the United Kingdom are equipped with batteries, and several systems have more than one.

I am interested in Dr. Morris's remarks, but I am afraid that there is a want of appreciation of the fact that in many small tramway stations it is not possible to keep the cell-voltage at a figure to obtain the results suggested, not only by Dr. Morris, but by other speakers, as it is quite an ordinary occurrence in these small stations for the cell-voltage to rise to 2·5, and it is just the rapid fluctuation of the cell-voltage from 2·5 down to 2 volts which has caused most of the trouble in connection with automatic boosting arrangements. Of course, if a booster takes such time to reverse its magnetism as mentioned by Dr. Morris, a rapid regulator is useless, but such a booster would be useless on a tramway system with rapidly fluctuating loads. Dr. Morris raises the point as to whether a Thury regulator could not be compounded. As this is worked on the voltmeter principle, I do not in the least see how it could be done.

Dealing with Mr. Allingham's remarks, I quite agree that the windings of the small motor on the regulator are somewhat the same as those of the Turnbull and McLeod booster, but the addition of the balancing coil makes all the difference. The regulator is, in a way,

a differentially wound booster, with the difference that it does not boost, but makes something else do so. The position of the booster with respect to the regulating gear is quite immaterial. I would like to point out that the regulator can be adapted to any booster regardless of its magnetisation curve, and whether it is being worked with saturated field or not; it is simply a matter of calculating out the regulating resistances to obtain suitable steps on the regulator. There is no necessity in this regulator to adjust the series diverter when once it has been fitted up, and the small adjustment necessary to get the right proportion of the outside load diverted through the No. 1 Coil is easily made on the job, a few saw cuts in the strip being sufficient to give final adjustment, in the same way as the adjustment of an ammeter shunt is effected. Mr. Allingham also mentioned the suggestion that the series coil of an ordinary differentially wound or special automatic booster could be made to compensate for the drop in the line. It appears somewhat curious that this has, as far as I am aware, never been done, and I imagine that it would have been tried or claimed unless there had been some particular reason why it would complicate matters. Undoubtedly, with the Highfield and other systems, the volts do drop at the end of the line considerably and frequently, to the annoyance of the traffic manager who is trying to keep even speeds. Mr. Tilney.

With regard to the Thury regulator and Mr. Bornand's criticisms, it was interesting to me to hear his statement with regard to what the regulator will do. Undoubtedly, two years ago, this regulator would not reverse, and I suggested at that time to Mr. Bornand that it would be an advantage if it could be made to reverse, and we now see the result. The regulation of 4 per cent. which I quoted is 2 per cent. on either side, and not 4 per cent. on either side, and I believe there are few central stations in the United Kingdom where as close regulation as this will be found. Mr. Bornand's regulation curve, as shown on the screen, was very close, but I am curious to know how it was obtained. It, nevertheless, would allow for an enormous drop in volts at the end of the line, and what tramway engineers require is not a straight line curve in the station, but a straight line curve on the trolley line. The ease with which my regulator can be made to compound up is a great advantage.

Mr. Siddeley's point on the use of boosters with full current and no field is covered by my answer to Mr. Allingham. As regards laminated fields, I expressly state that regulation is better with them, but the curves in the paper show what can be done with solid polepieces. I doubt if it would be possible to rewind a booster on the Turnbull and McLeod principle unless the carcass was much larger than was needed in the first instance, and also it means putting the machine out of use while the alteration is being made, which may indirectly cost a not inconsiderable amount. As regards the use of compound generators, I doubt if any system will prevent a compound generator from taking too much load when running with a battery, and I should never suggest the additional expense of the compound windings. As regards

Mr. Tilney. sluggishness due to diversion, it does not appear to affect the apparatus as far as one can observe. Mr. Siddeley's idea of a battery fully charged and mine do not agree, neither do my observations of what is required in the way of regulation agree with his.

I do not consider that a battery is approaching being fully charged till the cells rise to 2·5 volts, and at this figure much coarser regulation is permissible, as it takes a much greater variation in volts to produce a change from, say, 100 amperes charge to 200 discharge when the cells are up to 2·5 than is the case when the cells are at, say, 2·2 volts. This will, I think, be easily seen if one considers that the cells in question will stand up to 1·95 to 2 volts each when discharging at 200 amperes, and will, therefore, for a 500-volt supply, require 20 to 30 volts boost out, and will in one case take only about 28 volts boost in to charge at 100 amperes, and in the other will require just about 100 volts boost in. I have always found in practice that the higher the cells are above 2·2 volts, the coarser can be the regulation, whether by hand or automatical, but in the last case it is a question of must be, not can be, to get the best results.

In dealing with Mr. McLeod's interesting communication, no doubt there are boosters in existence that will not carry the full-load current without sparking unless they have strong fields. Personally, I do not quite know how they are made to work as ordinary non-reversible boosters if this is the case, because in practice it is quite an ordinary thing to have to commence a charge with full current and practically no boost on the machine at all. This, I think, will be quite obvious from the fact that if the cells are standing at 2 volts, and there are 240 cells, the total voltage of the battery is 480, and the 20 volts difference between this and the line will account for a very considerable current into the battery. It will be of interest to Mr. McLeod to hear that with the regulator in question, which is in use at Glossop, we are able to keep the load on the generators constant within 10 amperes. The regulator has only been in use about three weeks, but I do not anticipate any trouble, even if it had been in use for three years. There is absolutely nothing to get out of order, and all that is required is for the contacts to be wiped over with a little rag and methylated spirit about twice a week.

I am afraid that Mr. Highfield does not quite follow the meaning of the paragraph to which he takes exception. I did not intend to convey in any way that a larger battery was necessary as the load grew. What I was endeavouring to point out was that, assuming, in the first place, that a generator is in use of, say, 400 amperes capacity, and that the battery will take a charge at 400 amperes and discharge at, say, 800, as the system grows the maximum will perhaps rise to 2,000 amperes. In that case, it will have been necessary to use another generator in parallel with the 400-ampere machine and the battery—say an 800-ampere machine. This will give a generator output of 1,200 amperes, and supposing that the variations below that are greater than the battery can take as charge (the minimum current being about 500 amperes), the Highfield booster will attempt, as far as it is able—and

it will make a very good attempt—to keep the volts level by overloading itself or trying to, and putting more current into the battery in charge than it ought to. If it cannot do this, there is absolutely no alternative but for the line volts to rise very considerably at these points of minimum current. That is the meaning that I wish to convey in the paragraph which Mr. Highfield criticises. Mr. Highfield also takes exception to another part of the paper, and raises the same point that has been raised by several other gentlemen in the discussion when he says that if a battery of the proper size is put in it will not be necessary to use a booster. This, of course, is perfectly true, but unfortunately we cannot always put in as large a battery as we should like, and the reason, I suppose, why automatic boosters have been developed is that there is a certain economic figure beyond which it is not advisable to increase the size of a battery for a given load, and in order to obtain satisfactory regulation it is more advisable to spend, say, £300 on a booster than to spend £2,000 on larger cells. Mr. Tilney.

Mr. TILNEY (*communicated*): Since reading my paper I have, with the kind permission of Dr. Morris, been able to time the Thury regulator at the University, which, however, is for fine, not rapid regulation, and I find that when the load is suddenly altered by hand it takes the regulator five seconds to correct for a drop of 15 volts, corresponding, say, to 35 volts on a 550 circuit. This may be good enough for some people, but it does not meet with the requirements of our central station work, and though I am convinced that the Thury regulator has done better than this, it is somewhat astonishing to me that Mr. Bornand has not produced particulars as to how this regulation was obtained. As a matter of fact, in my system, while watching the line voltmeter and total current ammeter, as well as an ammeter in circuit with the No. 1 Coil, I find that the ammeter in circuit with the No. 1 Coil does not appreciably lag in action behind the ammeter of the main circuit, and that though, in the event of a very heavy load being thrown on, there is a momentary swing on the voltmeter, the needle returns to, or approximates to, its original position immediately, the little armature of the regulator motor moving with the swings of the main ammeter needle.

LEEDS LOCAL SECTION.

THE RECTIFICATION OF ALTERNATING CURRENTS.

By P. ROSLING, Member.

(*Paper read at Meeting of Section, January* 18, 1906.)

The rectification of alternating currents has been, until quite recently, effected by means of a rotating commutator running synchronously with the periodicity of the supply, and, owing to the variation in the lag or lead of the current wave as compared with the wave of electromotive force, it has been found very difficult to run such apparatus without destructive sparking. As, however, such machines are not likely to be used in the future, they have now only an academic interest as forming part of electrical history.

The action of a motor generator can certainly not be called rectification, and even a rotary converter cannot be properly called a rectifier, as it has a compound effect of a rectifier and a motor-driven generator, the latter action being the predominant, as only for the instant when the commutator bar, which is directly connected to the slip-ring connection, is in contact with the continuous-current brush does the current from one side flow straight through to the other side; at other times it has more or less of a motoring action, the resultant continuous current being due to the rotating armature acting partly as a continuous-current armature and partly as an alternating-current reactance coil. Neither the motor generator nor rotary converter is in the immediate future likely to be superseded for the conversion of large powers at comparatively low potential from alternating to continuous current, but for smaller powers there are now two systems of rectification in commercial operation, both of them having the supreme advantage of having no moving parts, viz.:—the electrolytic rectifier and the mercury arc rectifier.

THE ELECTROLYTIC RECTIFIER.—This apparatus consists of plates of an alloy mainly composed of aluminium, acting as cathode, suspended in a solution of borate or phosphate of ammonium or other salt capable of rapidly altering the condition of the polarising layer or film formed on the passage of an alternating current, such as salts of tartaric, oxalic, acetic, or gallic acids; the electrolyte may be contained in lead cells, which would then form the anode.

When a single-phase alternating current is switched on to such

a combination, if the direction is positive from the lead to the aluminium, it passes on through the circuit; if, however, the direction is positive from the aluminium to the lead, a polarising insulating film is immediately formed on the lead which offers a high resistance and opposes the passage of the current; when the polarity reverses and the current flows from the lead to the aluminium plate, the film undergoes alteration and the current passes readily; if only one semi-phase is required a single cell is sufficient, giving an interrupted unidirectional current of as many pulsations as the periodicity of the alternating-current circuit. In usual practice both semi-phases are used, either by grouping four cells, as in the Leo Gratz method, so that they allow the current to pass through two cells in series, turn and turn about, as shown in Fig. 1, or as in the Churcher method, where one platinum

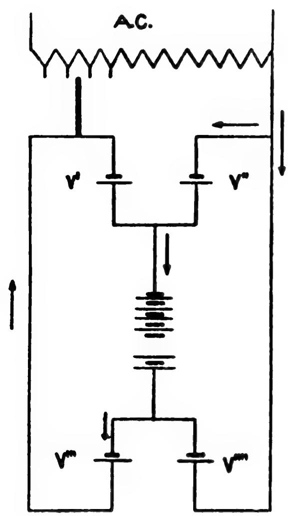

FIG 1.

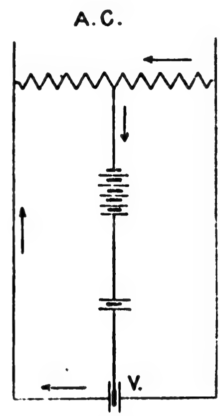

FIG. 2.

or lead plate and two aluminium plates are suspended in one cell, the current coming through the working circuit from the middle point of a reactance coil (Fig. 2). In Fig. 1 the path of the current during one semi-cycle is shown by the arrows; it passes through cell V″, the accumulator, and V‴, the insulating film forming on V′, the aluminium to lead path, preventing the current short-circuiting across to the other side of the alternating-current circuit; on the reversal of the polarity the current flows through V′, the accumulator, and V⁗, V″ now forming the "closed door." The current thus passes in the same direction through the accumulator in pulsations of twice the periodicity of the alternating-current circuit. Fig. 3 shows the rectification of the alternating current into a pulsating unidirectional current. Fig. 2 shows the Churcher arrangement; the path during one semi-cycle is shown by arrows;

the current flowing from the middle point of the reactance coil through the accumulators and one half of the rectifier cell V; on reversal of polarity the current flows through the other half of the reactance coil, the accumulators, and the other half of the cell V. In both systems the reactance coil can be arranged with multiple tappings so that the correct electromotive force for the work to be done can be efficiently obtained; the pressure across the direct-current circuit being approximately 90 per cent. of the pressure between the tapping and the terminal end of the reactance coil. Rectifiers of this description may be used on 50-100 cycle circuits where the alternating-current pressure does not exceed 140–150 volts, and where the temperature of the electrolyte can be kept below 120° Fahr.; above this temperature the efficiency falls off very rapidly. In a test made by Mr. Horace Boot of an electrolytic rectifier arranged as in Fig. 1 and known as the Nodon valve, an overall efficiency of 65 per cent. was obtained on apparatus charging cells (50 amperes × 118 volts); the efficiency being the ratio of the alternating-current watts taken from the mains to the direct-current watts put into the cells as measured by recording wattmeters; this result compares favourably with a motor generator of similar capacity, which, over the whole run, would not give more than about 55 per cent. efficiency. It is usual to insert a resistance between an electrolytic rectifier and the alternating-current circuit, otherwise it sometimes happens that there is a large rush of current on first starting, especially if the plates have been left in the electrolyte; this resistance can be short-circuited when the apparatus has started working. The loss in an electrolytic rectifier is principally leakage current, which does not pass through the direct current or load circuit, but is expended on heating the electrolyte and is dependent upon the electrode potential at the film, the quality of the aluminium electrode and the particular electrolyte used, and as the losses increase enormously if the temperature of the electrolyte exceeds 120° Fahr., it is necessary to provide some means, such as cooling tubes or forced ventilation, to keep the apparatus below that temperature. In the above test there was a drop of 8 volts on the cells, or 4 volts per cell, and a loss of 22 amperes out of 72 in the four cells. Fig. 4 shows the connections for a 2-phase circuit. A 3-phase circuit would be similar, but with one pair of cells less. With two and three phases in use, the current flowing through the working circuit would be pulsating, but to a much less degree than with single-phase; Fig. 5 shows the resultant current

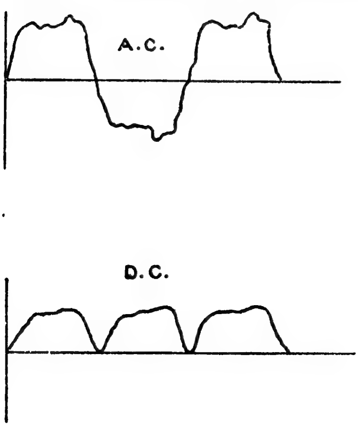

FIG. 3.

from a 2-phase circuit, the dotted lines being the two rectified single-phase currents in quadrature, and the hard line being the resultant current through the accumulators.

The Mercury Arc Rectifier.—Gases and vapours in their normal state are practically insulators, but there are various ways in which their insulating properties may be broken down, as, for instance, raising them to high temperatures, also when Rontgen, Lenard, or cathode rays are passed through them, or, in short, when the gases or vapours are ionised, as in an electric arc, where a bridge of conducting vapours consisting of the material of the negative or cathode is continually produced and carried over to the positive pole. An electric arc cannot establish itself; it must be produced either by drawing apart two terminals, or by an electrostatic pressure sufficient to jump across the gap between two terminals, or by bringing another arc flame

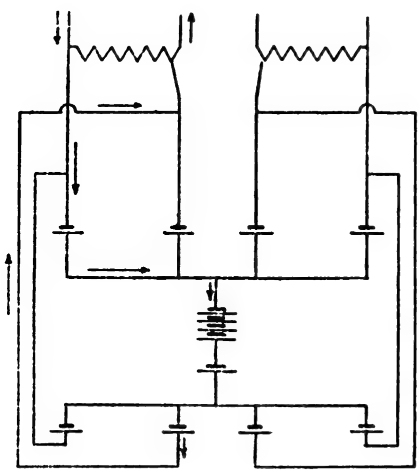

Fig. 4.

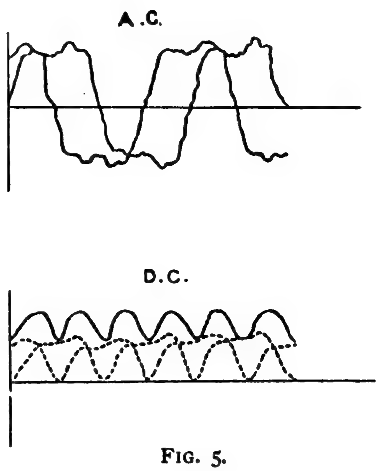

Fig. 5.

into the gap; if an arc is stopped and the cathode blast interrupted, as in an alternating-current circuit, the arc does not restart unless the electrostatic voltage is higher than the striking voltage, at arc temperature, between the electrodes. With mercury vapour the difference between the electrostatic pressure required to start the arc and the E.M.F. required to keep an arc flowing is very great, this being due to the low temperature of the arc; that is, the resistance of mercury vapour in the normal state is very high, but, in the presence of cathode rays, it is so low that the vapour becomes a good conductor, requiring only a few volts to sustain an arc. When a mercury electrode is used as a cathode, ionised mercury vapour is thrown off; thus, in an ordinary mercury vapour arc lamp, the negative terminal is mercury, the other terminal being any suitable

material, as graphite, and, when this lamp is connected on a continuous-current circuit and the arc is once started, it continues to exist until the pressure is switched off, or falls too low to overcome the resistance and back electromotive force of the arc. If the polarity is reversed and the graphite terminal is negative, it would require an extremely high potential to maintain an arc after it was started. If, therefore, it were possible to start an arc in a mercury arc lamp at every change of polarity on an alternating-current circuit of under 25,000 volts pressure, current would only flow when the mercury terminal was negative, and there would be a pulsating unidirectional current flowing through the lamp.

This action is taken advantage of in the mercury arc rectifier, which, for a single-phase circuit, is an exhausted glass vessel containing two anodes, one cathode, and one starting anode. The two anodes are connected across the terminals of the alternating-current line and become alternately positive and negative. While either anode is positive there is an arc carrying the current between it and the cathode.

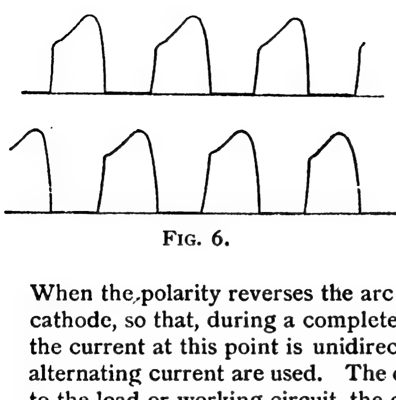

FIG. 6.

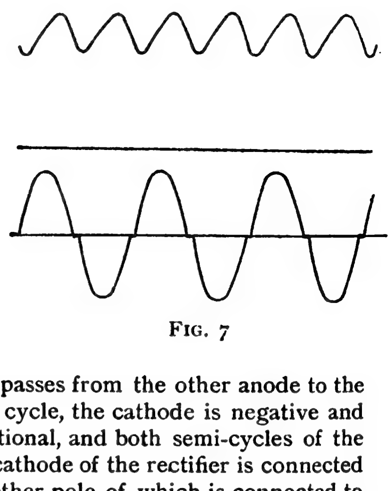

FIG. 7

When the polarity reverses the arc passes from the other anode to the cathode, so that, during a complete cycle, the cathode is negative and the current at this point is unidirectional, and both semi-cycles of the alternating current are used. The cathode of the rectifier is connected to the load or working circuit, the other pole of which is connected to the middle point of a reactance coil, which is connected across the alternating-current circuit (see Fig. 8). Without some means of continuing the arc, or establishing it at every reversal of polarity, the rectifier would not work, as the arc would stop at every reversal of the alternating current; although the current is at zero for an infinitesimally short time, yet this interval, even on high periodicity circuits, is sufficient for the cathode to lose its excitation and the arc to go out. A reactance coil is therefore so arranged that the current is held over the zero value and the pulsations are smoothed out, the current at the cathode becoming not only unidirectional but a true direct current with pulsations of small amplitude. Fig. 6 shows the relations of simultaneous values of currents in the two anodes, and Fig. 7 shows the

resultant continuous current at the cathode, compared to the impressed E.M.F. The action of the reactance can be seen from Fig. 6; the wave is no longer a sine wave, the reactance coil having sustained the current at a higher value, and the current waves in each anode overlap by an angle of approximately 20 deg., thus eliminating the zero points previously mentioned. The initial ionisation of the mercury vapour is accomplished by a small starting anode C, Fig. 8, which is brought into contact with the cathode by a mercury bridge formed by slightly shaking the tube. The breaking of this mercury bridge starts a small initial arc, and the arc thus obtained excites the cathode, giving the necessary ionised vapour, which enables the working anodes to immediately become active and the tube to start. Fig. 8 shows the connections of a rectifier diagrammatically, the plain arrows marking the path of the current at any moment, and the arrows in circles showing the path on the reversal of polarity. It will be seen that the circuit from the alternating-current terminal is composed of a rectifier arc, the load, and one of the reactance coils; the other coil is at the same time discharging energy stored up during the previous half wave, when it was in the line circuit. Assuming an instant when H of the supply transformers is positive, the anode A is then positive and the arc is free to flow between A and B, B being the mercury cathode. Following the direction of the arrows still further, the current passes through the load J, through the reactance coil E, and back to the transformer. A little later, as the impressed E.M.F. falls to the limiting value sufficient to maintain the arc against the counter E.M.F. of the arc and load, the reactance E, which till now has been charging, now discharges, the current flow being in the same direction as formerly, serving to maintain the arc in the rectifier until the E.M.F. of the supply has passed through zero, reverses and builds up to such a value as to cause A′ to have a sufficiently positive value to start an arc between it and the cathode B; the reactance coil E continues to discharge, but through the arc A′B. Consequently, the arc A′B is now supplied with current partly from the transformer and partly from the reactance coil E. The charge and discharge voltage of one reactance coil is clearly shown in Fig. 9, showing approximately constant discharge value in its relation to impressed E.M.F., and the voltage across the arc AB or A′B is given in Fig. 10, showing a drop of 14 volts while the arc exists, in its relation to impressed E.M.F. The measurement of

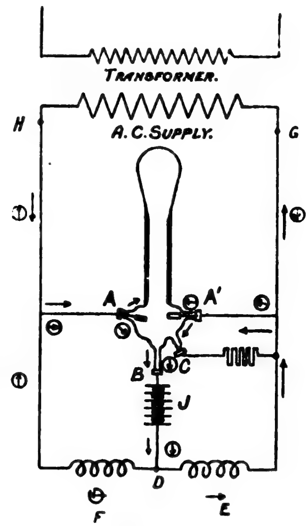

FIG. 8.

the two halves of the cycle shown in Fig. 10 indicates the length of time the arc holds over the zero point.

It will be seen that while both arcs are flowing from anodes A and A′ there can be no potential difference between the anodes, but as the electromotive force of the transformer secondary, or the supply mains, must more or less follow the primary electromotive force wave, the difference must be taken up by the reactance, so that while both arcs flow in the rectifier, the reactance consumes the electromotive force of the transformer secondary at the start of the current flow, and produces voltage near the end of the current flow of each half wave; between these times the reactance coil has practically no effect. The amount of reactance inserted in the circuit when the above curves were taken reduces the pulsations of the direct current sufficiently for all ordinary commercial purposes, but when it is advisable to still further reduce the amplitude of the pulsations, more reactance can be used, with a very slight reduction in the efficiency; with a suitable reactance the pulsations can be so reduced

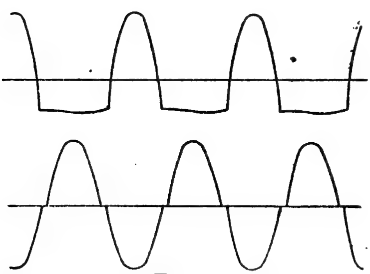

FIG. 9.

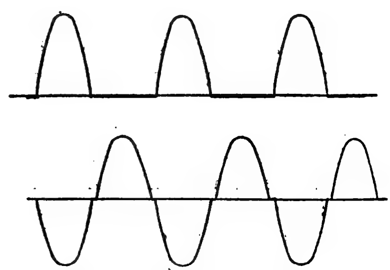

FIG. 10.

that the rectifier can be used floating on a battery, for telephone work, giving no appreciable hum. It is evident that the reactance must be designed to suit the nature of the load, as with a pure resistance load it is only necessary to have sufficient to keep current flowing when the alternating potential falls below 14 volts, the voltage required for the mercury arc, whereas, when charging accumulators, sufficient reactance is required to keep the arc when the alternating current drops below the back electromotive force of the cells, plus the 14 volts for the arc, and, as the alternating-current voltage should not be much higher than the cell voltage, the reactance coil has to keep the current flowing through quite a considerable proportion of the cycle. Mercury arc rectifiers can be used on any practical voltage; the maximum voltage is at present unknown, as with a rectifier of proper design and vacuum a high-frequency oscillator giving an 8-in. spark between 1-in. spheres does not send a discharge through from anode to anode; small currents at 36,000 volts impressed upon the rectifier terminals have been rectified successfully, and a rectifier tube with 24,300 volts at its anodes and

6·25 amperes at 9,500 volts continuous current at the cathode, has been successfully used on a water resistance; that is, a load of about 60 k.w. has been rectified in a tube weighing a few pounds.

A high-tension rectifier is now in general use in Schenectady, supplying 57 series arc lamps, giving 4 amperes at 4,260 volts continuous current, having an overall efficiency of over 90 per cent., including losses in the alternating constant-current transformer, in the reactance coils used to carry the arc over from one semi-phase to the next, and in special reactance coils in the continuous-current circuit used to reduce the pulsations of the current, the loss in the rectifier itself being about 0·4 per cent. For ordinary commercial work off supply mains the rectifier can be designed for any standard pressure or frequency, the maximum continuous-current pressure being approximately half the alternating-current voltage, and the continuous current nearly double the alternating current, the ratios being varied by means of suitable tappings from the reactance coil. As the loss in the arc is constant, the efficiency, of course, varies with the direct-current pressure delivered; thus, on a test of a 30-ampere set giving 80 volts on the continuous-current side and working on a 220-volt alternating circuit, the overall efficiency was 75 per cent., but with 112 volts on the direct-current side the efficiency was over 80 per cent. This efficiency holds good down to quarter load; the power factor of such a set being practically 90 per cent.

To charge a battery so that the maximum battery efficiency can be obtained, comparing the watt input and output, it is necessary to reduce the rate of charge as the operation proceeds, so that with a motor generator starting at 30 amperes and an overall efficiency of about 65 per cent., the motor-generator efficiency falls off as the charge continues until it approaches the neighbourhood of 30 per cent., giving an average efficiency throughout the whole charge of, say, 55 per cent. Comparing the cost of running a mercury arc rectifier on cells taking 15 units in a five hours' charge at about 110 volts with the running cost of a motor generator, the saving would be approximately 8½ units, or, at 2d. a unit, 1s. 5d. per charge, and, as there is no part of the apparatus likely to wear out, other than the tube itself, there is nothing to set off against this saving, and should the tubes last, say, 1,000 hours (and some have been tested to 1,500 and 2,000 hours), the saving in current during the life of the tube would amount to £10 3s. 4d., or 30 per cent. of the current bill for the motor-generator set for the same work. Comparing it with an electrolytic rectifier of 65 per cent. efficiency, the saving on 200 charges of five hours each would be £7 1s. 8d., at 2d. per unit. For charging cells the mercury arc rectifier has a certain inherent regulation similar to a shunt-wound dynamo, the voltage at the cathode rising as the current falls, thus tending to compensate for the increase of the counter E.M.F. of the battery, so that the regulating switch need not be moved very frequently during the charge; the regulating switch being connected to the reactance coils, the efficiency of the apparatus is practically constant throughout the charge.

Three-phase current may be rectified into continuous current by means of tubes having three anodes, the load being connected between the cathode and the neutral point of a 3-phase star-connected reactance coil, and as with a 3-phase current there is no zero point, the continuous current has less pronounced pulsations, with the same amount of reactance, than with the single-phase system, as shown above with the electrolytic rectifier.

In concluding, I must express my regrets that I have not been able to put forward anything original on this subject, but trust that the information collected from various papers and periodicals—and especially from Mr. Wagoner's and Mr. Steinmetz's papers on mercury arc rectifiers, to whom I offer my sincere thanks—may prove sufficiently interesting as an introduction to what promises to be a new field in electrical work, as further developments both in class and capacity may be looked for in the future.

DISCUSSION.

Mr. Wilkinson.

Mr. G. WILKINSON: The author gives two methods whereby the rectification can take place by static apparatus. The first is the electrolytic rectifier. It was my fortune to get one of the first of these of a large size, that came to England from Paris, about three years ago. In order to give it a fair trial I thought that the best work it could be set to do was to supply current to a motor driving stoker shafting. This shafting was running twenty-four hours per day, for six days per week, and I thought that if it could supply direct current for this purpose we could trust it with any work. We procured a 6-H.P. motor and set it to work. It went for two or three days and then something went wrong inside, which the manufacturers put down to faulty electrolyte. This was renewed and the machine restarted. It worked for a day or two, when some trouble again ensued; this time they said it was due to the electrodes. New ones were put in and then the insulation failed and had to be renewed. After that it would run for twenty minutes or half an hour, and then stop, when we had to start the stoker steam engine. Every opportunity was given for putting the thing in order, but eventually the agents requested that the apparatus should be sent back. This was a rectifier of French design, and it was kept cool by an electric fan placed beneath the rectifier. I have not had any experience with the machine now on the market, and I do not know what improvements have been effected during the interval. I understand, however, that some progress has been made in the direction of making them more reliable. The efficiency obtained from the apparatus I referred to was about 60 per cent. With regard to the mercury arc rectifier, it is not an easy thing to say very much, or to criticise in detail an apparatus which one has the pleasure of seeing only in a photograph. I have had a considerable amount of experience in making mercury vapour lamps of various kinds, and I have been troubled by losing the vacuum. After running the early lamps for a short time the

vacuum was lost, viz., in lamps taking a current of half an ampere. After a considerable time I found that it was necessary to seal two or three platinum wires of small diameter in the glass rather than one larger one, in order that the good vacuum necessary might be successfully maintained. This points to a practical difficulty in these rectifiers when designed for heavy currents. On page 5 the author cites a case where one of these rectifiers is supplying 57 series arc lamps, but it is only furnishing the small current of 4 amperes at 4,260 volts. I think that an apparatus giving that output would be very little use in many of our supply stations. If the current was 400 amperes at 100 volts, or something like that, the apparatus would be more useful. In the third paragraph on page 6, the author mentions one of these rectifiers giving 80 volts and 30 amperes on the continuous current side. I think this is a step in the right direction, and that it will be a very useful apparatus for charging automobiles, but I am of opinion that what is really wanted is one giving 200 or 300 amperes at 200 to 300 volts, which could be used for charging batteries on a large scale. I would like some information as to the method of sealing the wires into the glass and making the vacuum reliable for heavy currents. The efficiency is exceedingly good, and I think it surpasses that of motor generators, at any rate as regards the smaller sizes. I do not notice anything about the cost of the apparatus or where it can be obtained. I would like to know what is the lowest periodicity at which they will work. From the illustration of the rectifier it appears that the apparatus is designed for a fair amount of current, because the extension at the top (the upper chamber) is large compared with the body of the rectifier, and, inasmuch as with a heavy current you want a big condensing chamber, I infer that the apparatus will take a heavy current. It would also be interesting to know the maximum amount of current put through and taken from this class of rectifier. Also whether there is any possibility of reversing the operation and taking out an alternating current, when a direct continuous current is supplied on the direct-current side. Mr. Wilkinson

Mr. T. H. Churton: How does the mercury rectifier or Nodon valve compare with the motor generator in prime cost and in working cost, including the cost of renewals and repairs? I think the author hardly gives the motor generator the credit it deserves. A test was made on a small set for charging accumulators for ignition work on motor cars. It was only a half-kilowatt set and the overall efficiency was 69·5. The author says that in order to get the greatest efficiency from an accumulator, it is necessary to reduce the charging current as the charging proceeds. I do not think that this is usually done in charging small accumulators, but that the current is maintained until the end of the charge, in which case the high efficiency of the motor generator is maintained. With a motor generator of large size it is quite easy to get an efficiency of 90 per cent. in the generator, and 90 per cent. in the motor, which gives 81 per cent. for the combination, and is higher than what would probably be obtained by the mercury rectifier for ordinary voltages. On Mr. Churton.

Mr. Churton. page 5 it is stated that the high-tension rectifier which is supplying 57 series arc lamps has an efficiency of over 90 per cent. This appears to be higher than the efficiencies previously mentioned, and I would like to know how this efficiency was obtained. On one occasion I noticed a rectifier at an exhibition which appeared to be an induction motor provided with a commutator and a number of rotating brushes. I cannot give a definite description of the apparatus, and I have not seen it at work, but the author may perhaps be able to give an explanation of it.

Mr. Parr. Mr. G. D. ASPINALL PARR: In recent years I have had two rectifiers through my hands, one of which is on the table, and is of the rotary type. A test of this machine was made recently. If the brushes are adjusted properly it will run practically without sparking, and will run for hours without the slightest attention, the motor also not sparking and having a very considerable torque. The other type of rectifier, which I had the privilege of testing a short time ago, is of a type in which there is a contact breaker something like an ordinary induction coil. The efficiency of this apparatus very much surprised me, being very low. The machine worked very satisfactorily so far as sparking was concerned.

In the rectifiers described by the author there is the distinct advantage that there are no moving parts, as very often the noise and buzz of a rectifier might be a serious disadvantage to the use of such an appliance. If one could get an inert appliance, for instance, with non-moving parts like a static transformer, which would convert alternating to direct current, there is no doubt that there would be a large future before it, providing it could be obtained at a reasonable price, and had a good efficiency and power factor.

Mr. Mountain. Mr. A. B. MOUNTAIN (Chairman): I am of opinion that in working crane motors, and particularly street lighting, it would be exceedingly useful if we could get a rectifier to convert alternating into direct current. I have been experimenting with mercury vapour lamps and I have obtained some wonderful figures. There is no question in my mind that, for street lighting, they will be largely adopted. With reference to the mercury vapour in this type of lamp, I would like to know whether Mr. Rosling can guarantee that no one would be seriously in danger of poisoning should one of these lamps break.

Mr. Rosling. Mr. P. ROSLING (*in reply*): Referring to Mr. Wilkinson's remarks, I think the stoker shafting running twenty-four hours a day is a very good test for any apparatus; the chief difficulty with electrolytic rectifiers has been that they are only serviceable for short runs, and if they are allowed to get hot the potential resistance of the anode disappears. I understand that the electrolytic rectifier now on the market is guaranteed for ordinary commercial purposes. Referring to the mercury rectifier, there is no trouble now in keeping the vacuum, but, owing to other circumstances, one of which is the temperature of the anodes, rectifiers for an output of more than 30 amperes are not yet on the market. The 30-ampere size would cost about £50 the 20-ampere size about £45, and the 10-ampere size about £38.

As to the reverse operation of the rectifier acting as a converter, such a device has been developed. A tube has four terminals as anodes and one terminal as cathode placed centrally as regards the four anodes; the diametrically opposite anodes are connected to the terminals of one primary and the other anodes, also opposite to one another and at 90 deg. to the first pair, to the terminals of the other primary of a 2-phase transformer; the middle points of the two primaries are connected together and to the positive terminal of a direct-current source of energy; the cathode is connected through a reactance coil to the negative terminal of the supply. Directly an arc is established between the cathode and one of the anodes it immediately jumps to a neighbouring anode, and so on round the tube, with a rapidity depending to a considerable extent upon the size of the anodes and their distance from the cathode. As an arc is established, current flows through one half of one of the primaries; an alternating magnetomotive force is thus produced by each primary winding, which generates in the corresponding secondary an alternating electromotive force; thus one revolution of the arc makes two complete cycles in each secondary, and as the anodes are at 90 deg. with one another, a regular 2-phase current is obtained from the two secondaries. The shifting of the arc from one anode to its neighbour seems to be due to the heat generated by the arc causing the resistance to rise until a point is reached when less resistance to current flow exists between the adjacent anode and the cathode; as this alteration of resistance would cause pulsation in the continuous-current circuit, a reactance coil is used as a storing and restoring agent, rendering the flow of power in the direct-current circuit more steady. Any other number of phases may be obtained by a suitable combination of anodes and transformers. Mr. Rosling.

Although, as remarked by one speaker, there has not been much improvement in the ordinary single-phase motor in recent years, yet the single-phase motor with commutator has been developed, and even the ordinary induction type motors of to-day are very much superior, mechanically and commercially, to what they were when they were first put on the market.

It is merely a commercial question as to whether a rectifier is better than a motor generator; but besides the prime cost (the figures given include the necessary switchboard and instruments) the running cost is less, and the rectifier, in the matter of convenience generally, is far superior to the motor generator. The efficiency of the arc-light generator is quite correct, and the figure includes the losses in the constant-current transformer; the efficiency of the rectifier tube itself is 99·6 per cent., the only loss being the 14 volts drop across the arc. The overall efficiency of the ½-k.w motor generator, stated to be 69 per cent., is remarkable, as it means that the loss in the motor and generator is only about 75 watts each; usually the mechanical losses of friction and windage would account for nearly that amount of power. There has been no trouble with disintegration of the graphite anode in the mercury arc rectifier.

Mr. Rosling. The rectifier exhibited by Mr. Parr is very interesting, but it has the disadvantage of being a machine with revolving parts, and one can easily imagine that, with a little inattention or carelessness, it would spark badly, and if it were allowed to run, when sparking, with anything approaching a good load, it would quickly burn out, as, being so small, there is very little radiating surface. The second rectifier he mentioned is more interesting scientifically than commercially, as, with the power factor and efficiency curves shown, it is not likely to help the station engineer at all with consumers.

Mr. Mountain's information on his experience in mill lighting with mercury arc lamps is most valuable, but, although you can tell different colours by it, yet you are liable to be misled when trying to choose tints of the same colour, at least for some colours. There should not be any danger of poisoning from the breakage of a mercury arc apparatus, as the vapour would immediately condense to minute particles of liquid mercury, and the amount that could be breathed in an ordinary room would be infinitesimal. Very small quantities of mercury are not considered by the medical faculty to be injurious to the system.

MANCHESTER LOCAL SECTION.

SINGLE-PHASE RAILWAY MOTORS AND METHODS OF CONTROLLING THEM.

By T. H. SCHOEPF, Member.

(*Paper read February* 27, 1906.)

Many papers have been read before the various technical societies, and articles have appeared in the technical press, on the subject of single-phase motors, treating of design, performance, and methods of controlling them, but it is intended in this paper to treat more particularly of a system with which the writer has had considerable experience during the early stage of its development and later application to commercial extent in electrification of railways, where it has proven successful, and it is hoped the paper will prove of interest and the information be of benefit to all engineers, and especially those associated with railway work.

MOTORS.

At the present time two types of single-phase commutator motor, having characteristics suited for railway requirements, have been developed and successfully manufactured on a commercial scale, viz., the plain series motor, having the magnetising coils on the field, and the series motor in which the exciting current is obtained from the armature by means of extra brushes placed midway between the main brushes.

The plain series motor has been referred to, in general, as the *series motor*, and the series motor with the excitation obtained from the armature as the *repulsion motor;* and, in order to avoid confusion, this nomenclature will be adhered to in this paper.

Both types of motor were designed and built in America, and after prolonged tests and careful study the series motor was adopted as giving better results and having characteristics more suited for general traction purposes. On the Continent, where the railway conditions differ from those in America, both types of motor are equally successful, judging by the contracts executed and in hand by the advocates of each type.

In the series motor a winding is distributed over the face of the poles, the flux from which neutralises the flux set up within the armature and thus annuls the induced voltage which would otherwise exist between the armature coils when passing the plane of commutation. The relation between the active fluxes may be seen, in convention, by referring to Fig. 1.

In Fig. 1 it may be noticed that the neutralising winding is in series with the armature and field windings, and may be considered as part and parcel of the armature winding, since the flow of current in the two must always bear a definite relation to each other, no matter which direction the armature may rotate. This arrangement of the windings is called forced neutralisation in contradistinction to induced neutralisation as shown in Fig. 2.

The relation between the armature and neutralising windings depends upon the pole pitch and number of armature slots.

The armature of a series motor is little different in appearance to

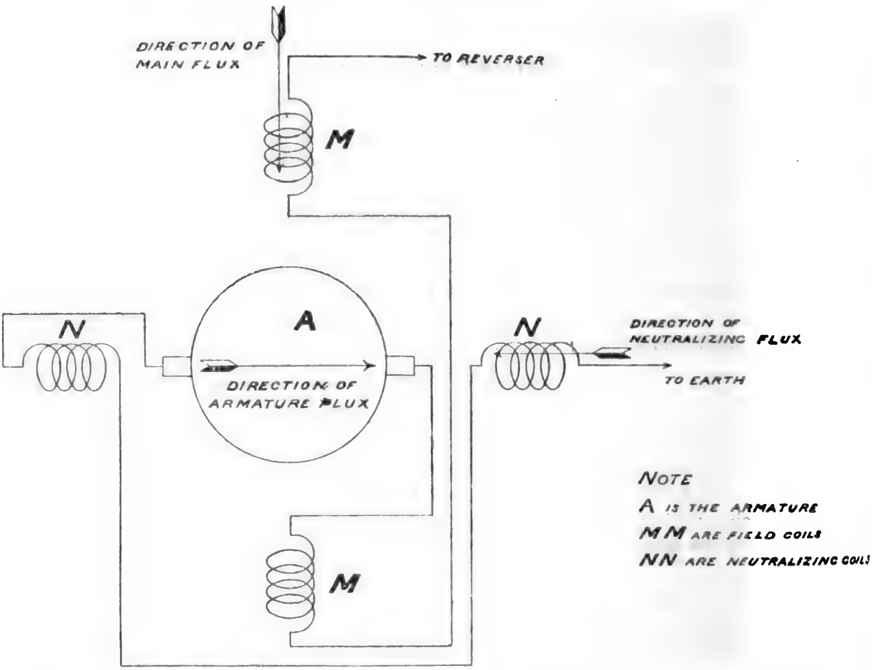

FIG. 1.—Single-phase Series Motor with Forced Neutralising Winding and showing Normal Distribution of Magnetic Fluxes.

that for a continuous-current motor. The winding is provided with high resistance leads connected between the coils and the commutator segments in such a manner as to come into action only when any coil is passing the commutating plane.

The series motor is wound for 250 volts across the terminals, which has the advantages of high insulation and less liability of breakdown. This will appeal to those who have had the responsibilities of the operation of tramway and railway motors at 600 volts or even higher voltages.

The trolley voltage is lowered to that required at the motor by an auto-transformer mounted upon the car, which permits of great flexi-

bility in adapting the system to the diverse conditions met with in general traction schemes. This system may be applied to any scheme and any trolley voltage (within practicable limits) by simply winding and insulating the auto-transformer according to requirements.

As an instance of the practicable application of such flexibility, we may consider the equipments supplied to the Indianapolis and Cincinnati Traction Company. These equipments operate in the town of Rushville, where the trolley voltage is not permitted to exceed 550 volts alternating current, and on the long section between Rush-

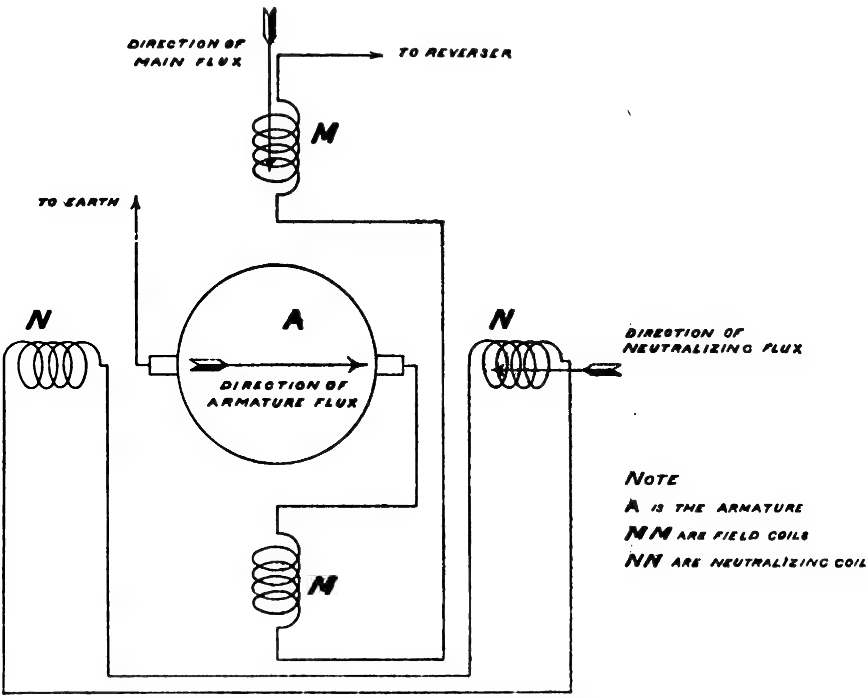

FIG. 2.—Single-phase Series Motor with Induced Neutralising Winding and showing Normal Distribution of Magnetic Fluxes.

ville and Indianapolis, where the railway is built upon private right of way, the trolley voltage is 3,300 volts alternating current; in the city of Indianapolis they operate on the existing tram lines at 550 volts continuous current. When passing from one section to another the re-grouping of transformer connections to give the desired voltage on the motors is effected, while the train is running at top speed, by a change-over switch. The change-over switch is under the control of the driver, operated by manipulating the master controller. The writer has seen this change-over effected at a speed of 50 miles per hour.

Another instance is a locomotive equipment supplied to the Swedish

State Railways for working a suburban service where the connectors from the auto-transformer are arranged for trolley pressure ranging from 3,000 to 20,000 volts.

The repulsion motor may have its field winding grouped for about 6,600, which is the practical limit of safe voltage on a traction motor. However, a given motor must have its field winding adapted to one voltage; and, if desired to operate the same equipment on any trolley voltage differing from this, a transformer is required for lowering or raising the voltage to the field winding. Under any circumstances a transformer is required to lower the voltage to that required for the armature.

Concerning the relative power factors of these motors, it will be found that, in general, engineers compare this characteristic at synchronous speed; whereas consideration should be given to the relation

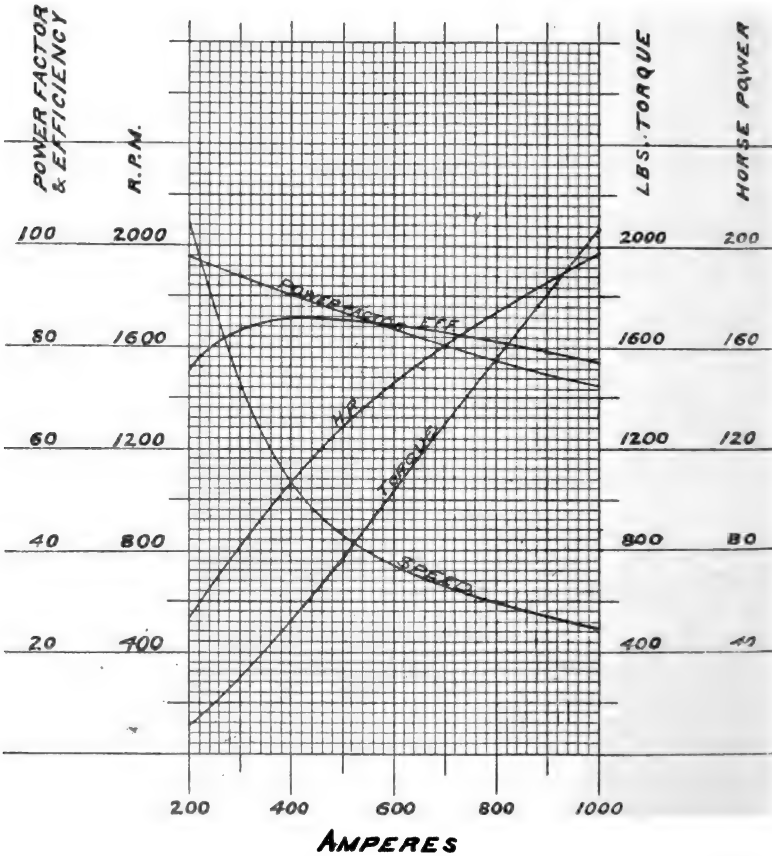

FIG. 3.—Characteristic Curves of a Westinghouse 150-H.P. Single-phase Series Motor, High Speed.

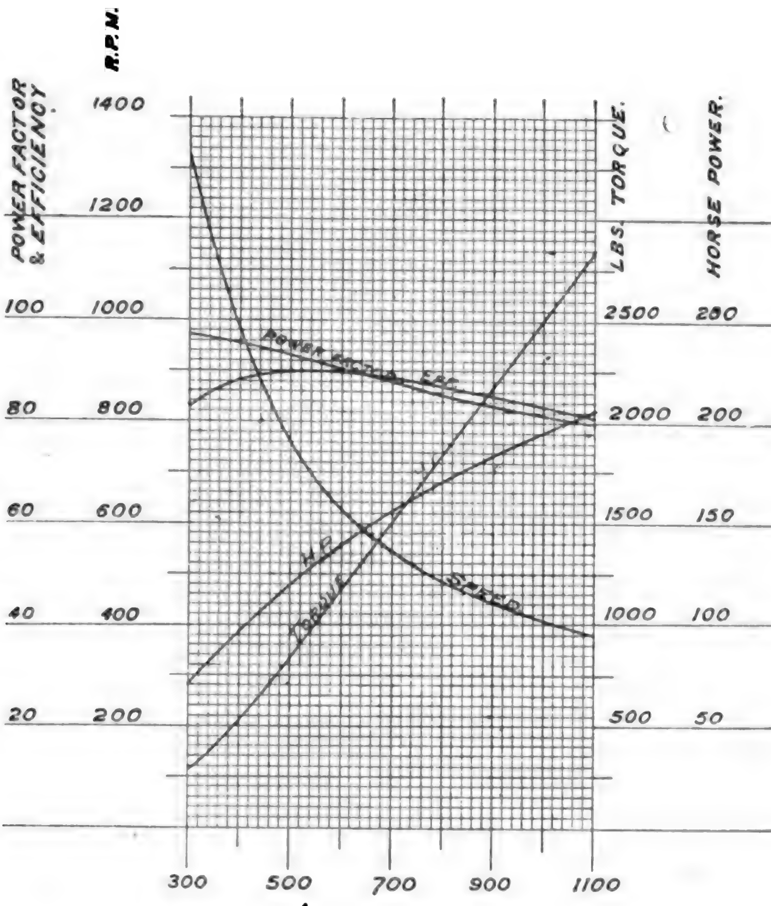

FIG. 4.—Characteristic Curves of a Westinghouse 150-H.P. Single-phase Series Motor, Slow Speed.

between full load, synchronous, and free running speeds, as this relation is the basis on which to draw logical conclusions.

The capacity of the single-phase motor to accelerate a train has been freely discussed, but there still seems to be doubt in the minds of some as to the starting torque which this motor will develop. Following is the result of a test which the writer made on a series motor with normal full load torque of 680 lbs. :—

The motor was fitted with a Prony brake, and when supplied with power at 173 volts across the motor terminals the armature developed a torque of 850 lbs., which is 25 per cent. above the normal full load torque, this limit rarely being approached in actual practice on electric railways. It may be of interest to know that the test was

carried further, and a torque of about 1,000 lbs. noted, but the scales were so sensitive that these readings could not be obtained accurately.

The capacity of the single-phase motor to fill the varying conditions to be met with on main line railways has been discussed at length, and a few remarks on this may be of interest. In the earlier single-phase motors the armature speeds were rather high, the normal full load armature speed of a 150-H.P. series motor being 930 r.p.m. (see Fig. 3), which made it more suited for long runs with few stops and speeds of 60 miles an hour. These are the characteristics of the motor with which the locomotive was equipped and referred to before as supplied to Swedish State Railways.

For suburban work with frequent stops and short runs, demanding a high rate of acceleration and high schedule speeds, but not high free

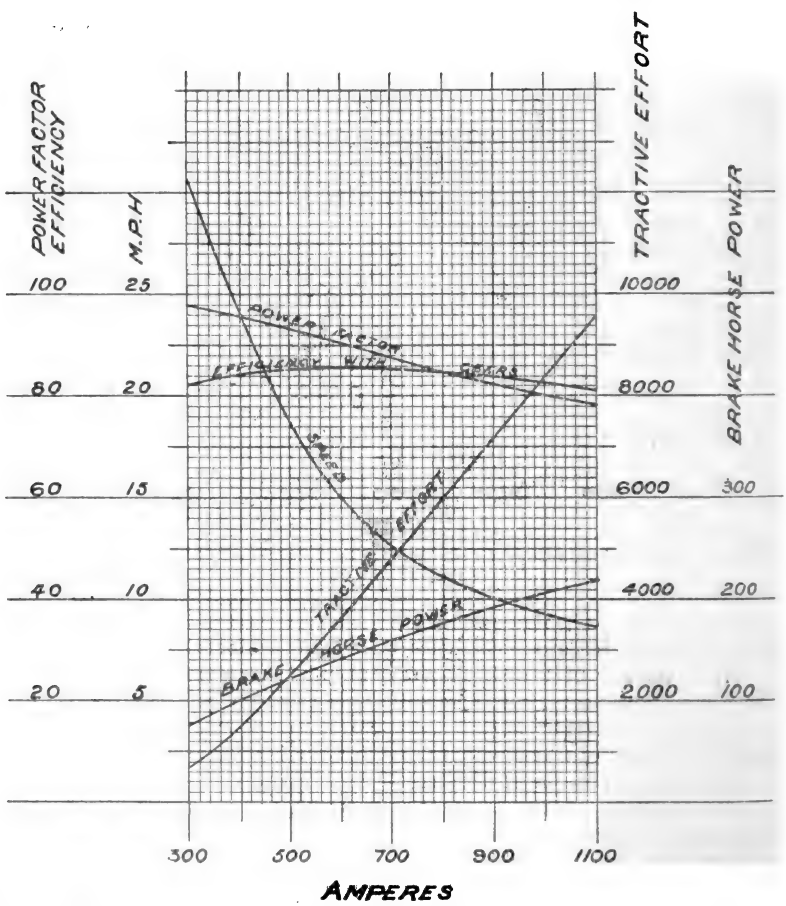

FIG. 5.—Characteristic Curves of a Westinghouse 180-H.P. Single-phase Series Motor.

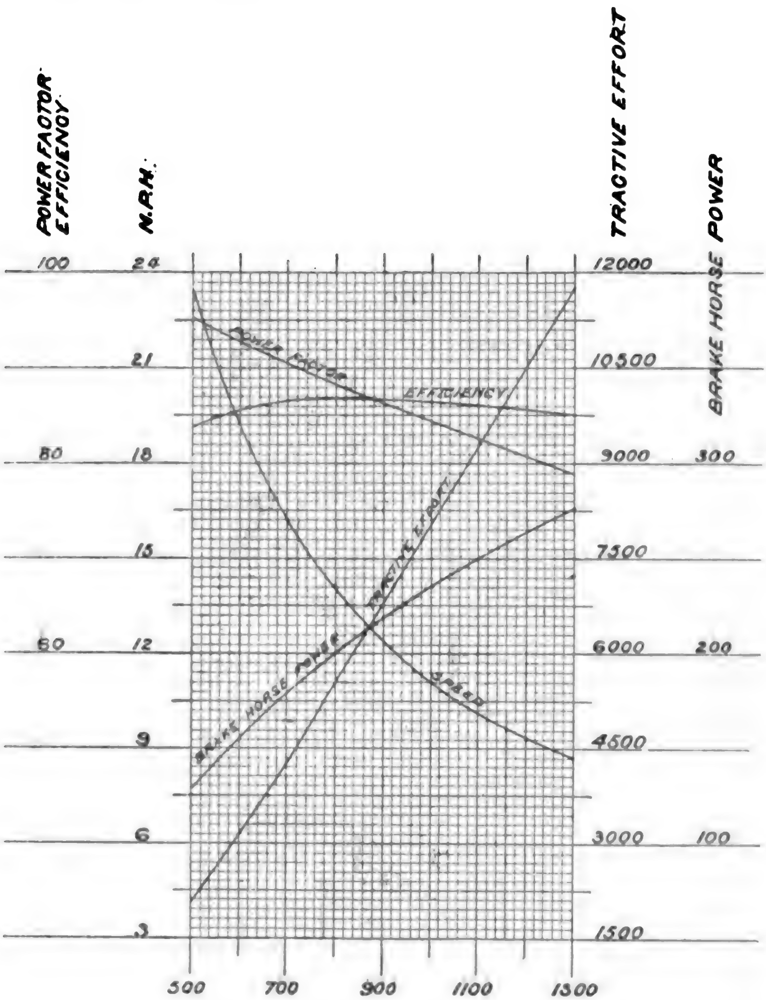

FIG. 6.—Characteristic Curves of a Westinghouse 250-H.P. Single-phase Series Motor.

running speeds, a 150-H.P. series motor has been developed with the normal full load armature speed of 535 r.p.m., the characteristic curves of which may be seen in Fig. 4.

For goods working a motor is required developing very great torque with high power factors and efficiencies at low speeds. The characteristic curves of such a motor are shown in Fig. 5. It may be mentioned that the continuous capacity of this motor is 140-H.P., which you will find, by reference to the curves, corresponds with 600 amperes at

the full pressure of 230 volts alternating current and a power factor of 90 per cent.

The characteristic curves of a 250-H.P. motor developed for the same class of service are shown in Fig. 6, and you may be interested to

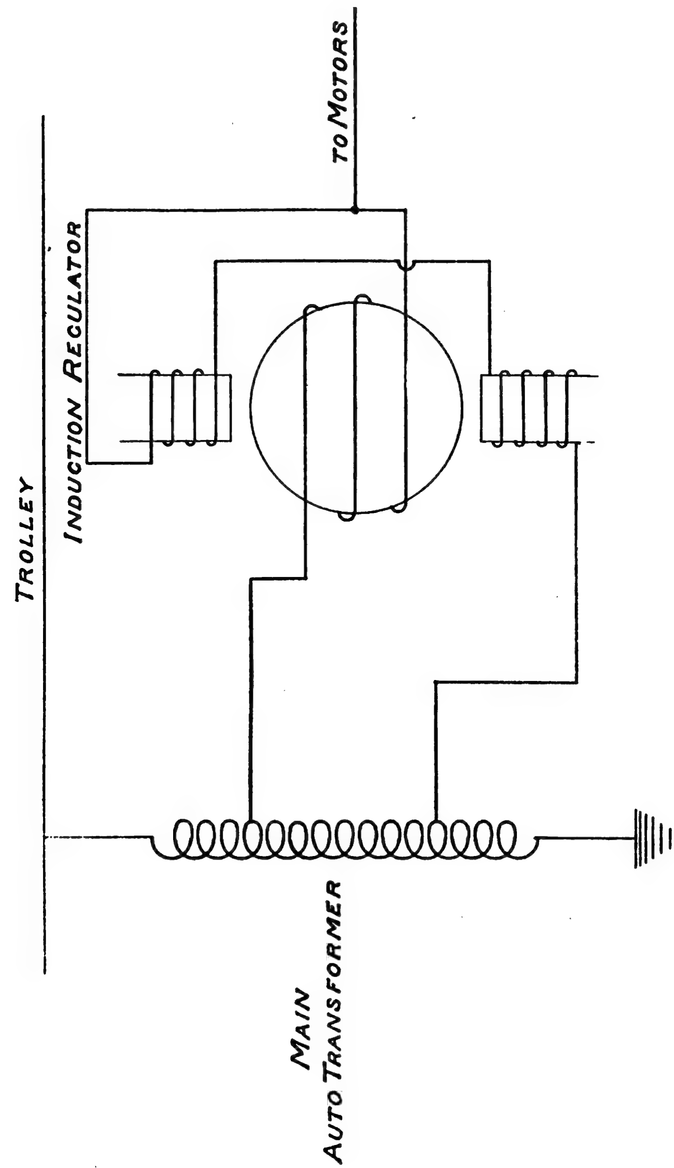

Fig. 7.—Arrangement of Auto Transformer and Induction Regulator. Starting Position.

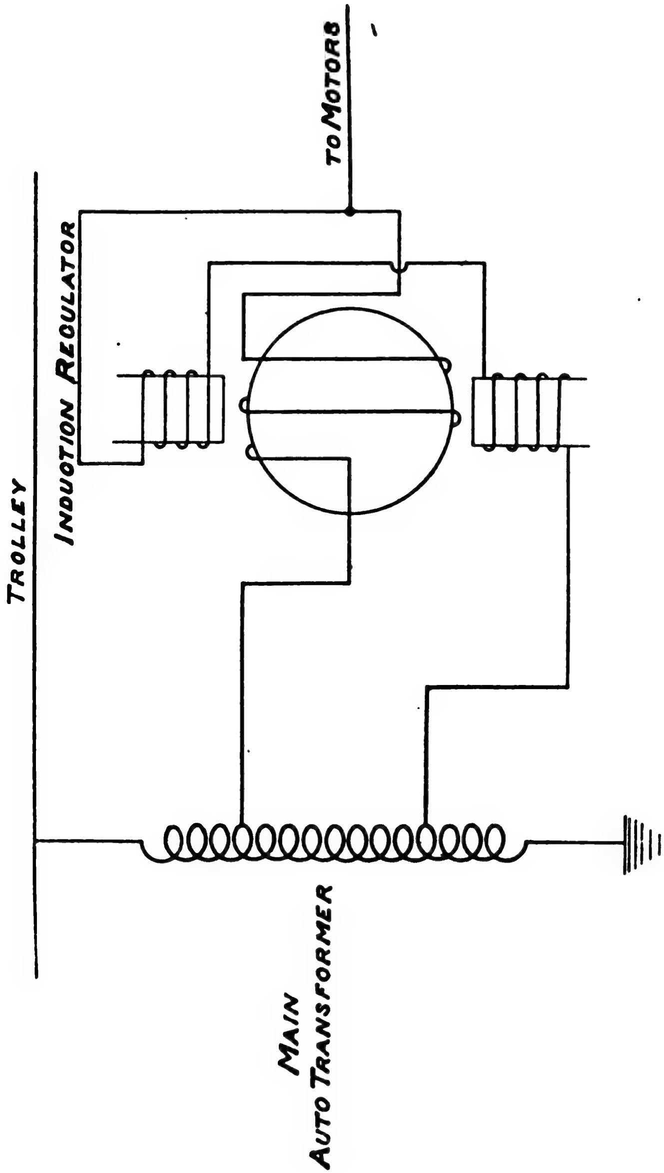

Fig. 8.—Arrangement of Auto Transformer and Induction Regulator. Position at 90° from the Start.

know that the large locomotive, the operation of which was demonstrated to the International Railway Congress last May (16, 1905) was equipped with six (6) of these motors.

CONTROL.

The ideal method of voltage variation in the supply of power to a single-phase motor is by means of an induction regulator, which pro-

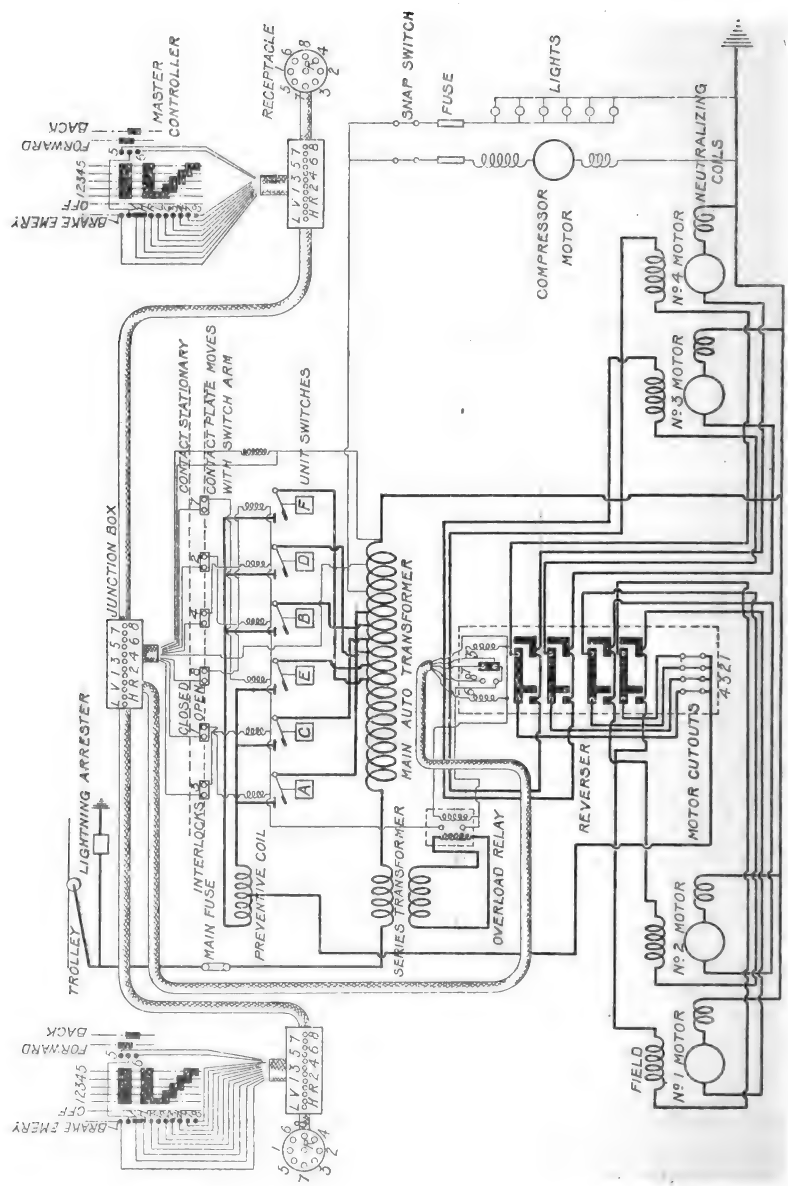

FIG. 9.—Wiring Diagram for a Motor Coach equipped with Single-phase Series Motors and Electro-pneumatic Multiple-unit Control System.

vides a uniformly increasing voltage without interruption to the supply.

At starting the voltage of the regulator is directly opposed to that of the auto-transformer. (See Fig. 7.)

The secondary is rotated at a predetermined rate through an arc of 180 degrees. The opposing voltage gradually becomes less until at 90 degrees it is nil. (See Fig. 8.)

When rotated through the second quadrant the regulator voltage is gradually increased and added to that of the auto-transformer until a position is reached diametrically opposed to that at starting, when full voltage is applied to the motors. This is the running position.

There are, however, objectionable features in the induction regulator. It introduces an additional reactance in the circuit, and therefore materially lowers the power factor of the system. During the period of acceleration, when the secondary is being rotated, the regulator vibrates and "hums" loudly, and the torque varies so that it is difficult to maintain uniform rotation.

The simplicity of the controlling apparatus for single-phase motors used on trains, having in their make-up more than one motor coach, is a subject which seems to occasion confusion in the minds of many who are not closely in touch with the operation of this apparatus.

The grouping of apparatus and electrical connections for a motor coach equipped with four (4) 100-H.P. series motors and arranged for multiple unit control is shown in Fig. 7; in this diagram it may be seen that any number of similar motor coach equipments may be controlled by the manipulation of a single master controller situated at any point in the train and electrically connected to the multiple control train line.

In this system of control the current is interrupted in the low-tension circuit, and a fuse only is necessary in the high-tension circuit, this being placed as near as possible to the current collector.

The power necessary for the auxiliary multiple control circuits is supplied at a pressure of 50 volts and obtained from a tap at the low-tension side of the auto-transformer. This power, through the manipulation of the master controller, is utilised to energise the operating magnets. The movement of the operating magnet armatures actuates the needle valves which regulate the admission and exhaust of the compressed air which works the unit switches.

It will be seen (by reference to Fig. 7) that there are six unit switches all contained in one case, but arranged in two groups of three switches each. The moving arms of the switches, in alphabetical progression, are connected to the taps from the auto-transformer, through the range of 160 volts, 180 volts, 200 volts, 220 volts, 240 volts, and 280 volts. The stationary contacts of the switches in each group of three are connected to a common omnibus line; these two omnibus lines are connected to the opposite ends of a preventive coil, the middle point of which is connected with the reverser and thence with the motors.

The preventive coil is proportioned so that, with different voltages applied to the ends, the mean is applied to the motors.

Grouping of the switches and the motor voltages for each position of the master controller is given in Fig. 8.

A series transformer is inserted in the high-tension circuit, and its secondary is connected to the operating coil of an overload relay. The relay interrupts the circuits of the operating magnets when the current passing through the primary of the series transformer exceeds a predetermined value. The relay is provided with a holding coil, which prevents the switches being closed, once they have opened an overload, until the master controller is returned to the neutral or "off" position.

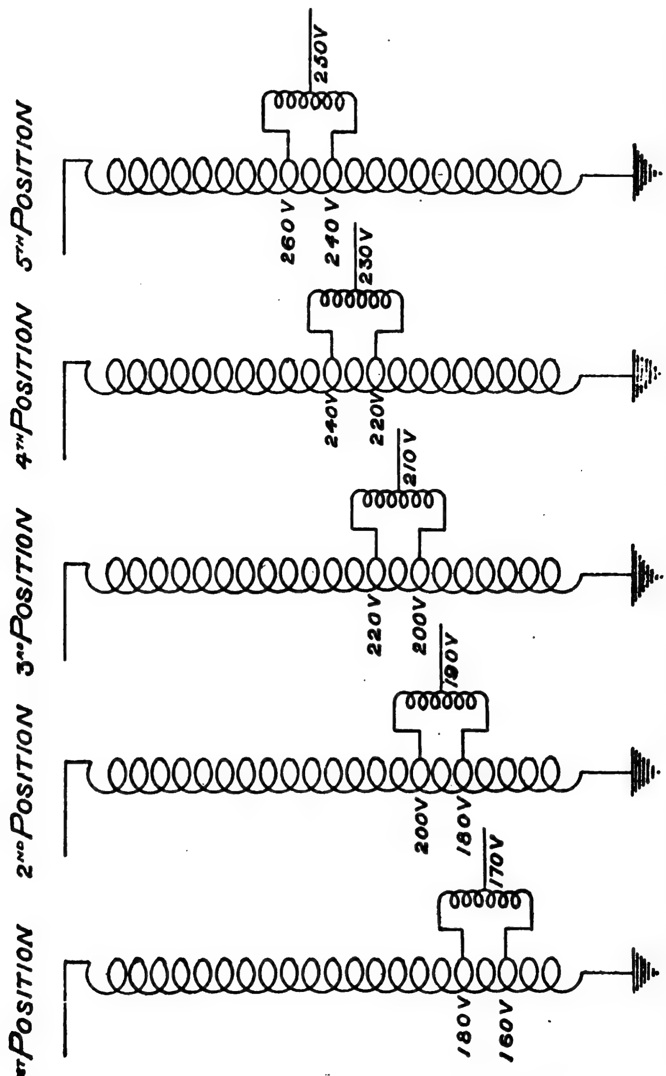

FIG. 10.—Diagram showing relative Electrical Connections between Auto Transformer and Preventive Coil and Voltages applied to Motors for the several Positions of Master Controller.

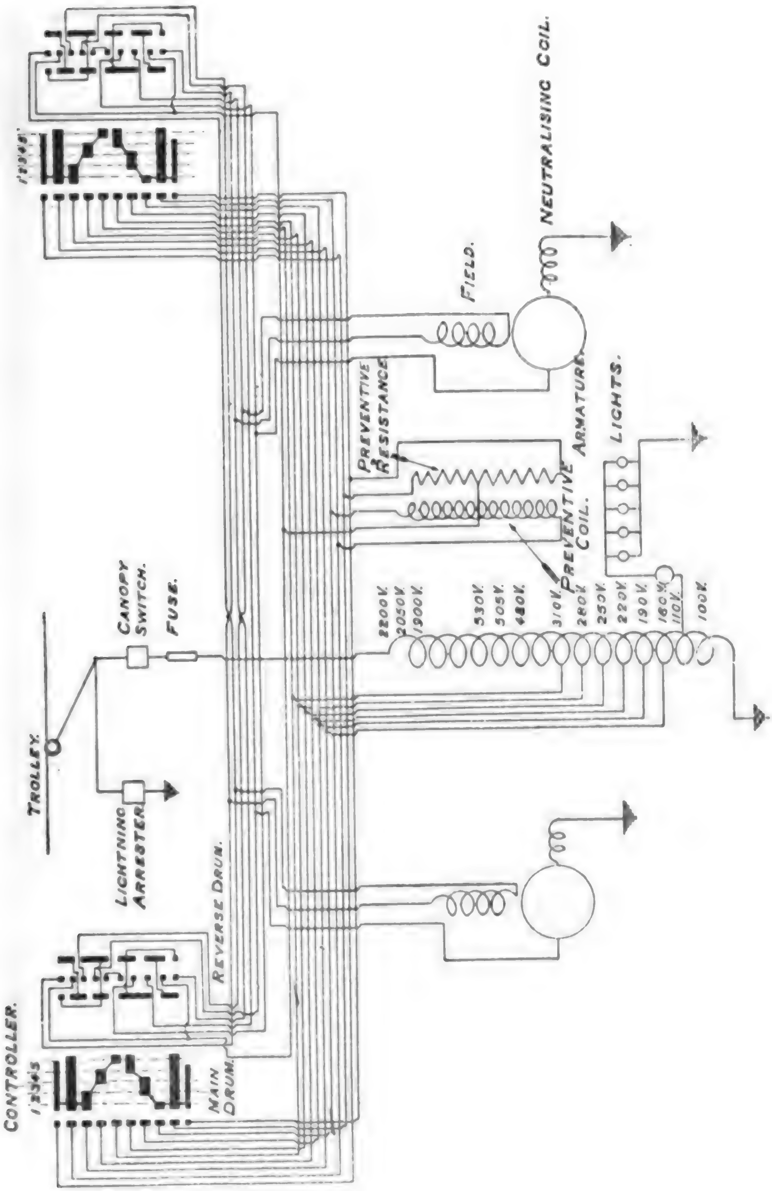

FIG. 11.—Diagram showing Connections between Electrical Apparatus on the Tram Cars of the Long Island Railway Company. Equipment consisting of two 50-H.P. Motors and Hand Controllers.

The operating magnets for actuating the needle valves are provided with laminated cores, since they are energised by alternating current.

The unit switches have to interrupt the motor currents when it is necessary to shut off power from the motors, and they are provided

with powerful magnetic blow-out, since these currents are large. The core of the magnetic circuit is built up of laminations.

Special attention may be called to the magnet which is marked "Magnet for Brake Valve." This is so interconnected with the master controller and driver's brake valve that the power will be shut off from the motors and the brake applied throughout the train should the driver remove his hand from the master controller for any reason. Both of these actions are effected simultaneously.

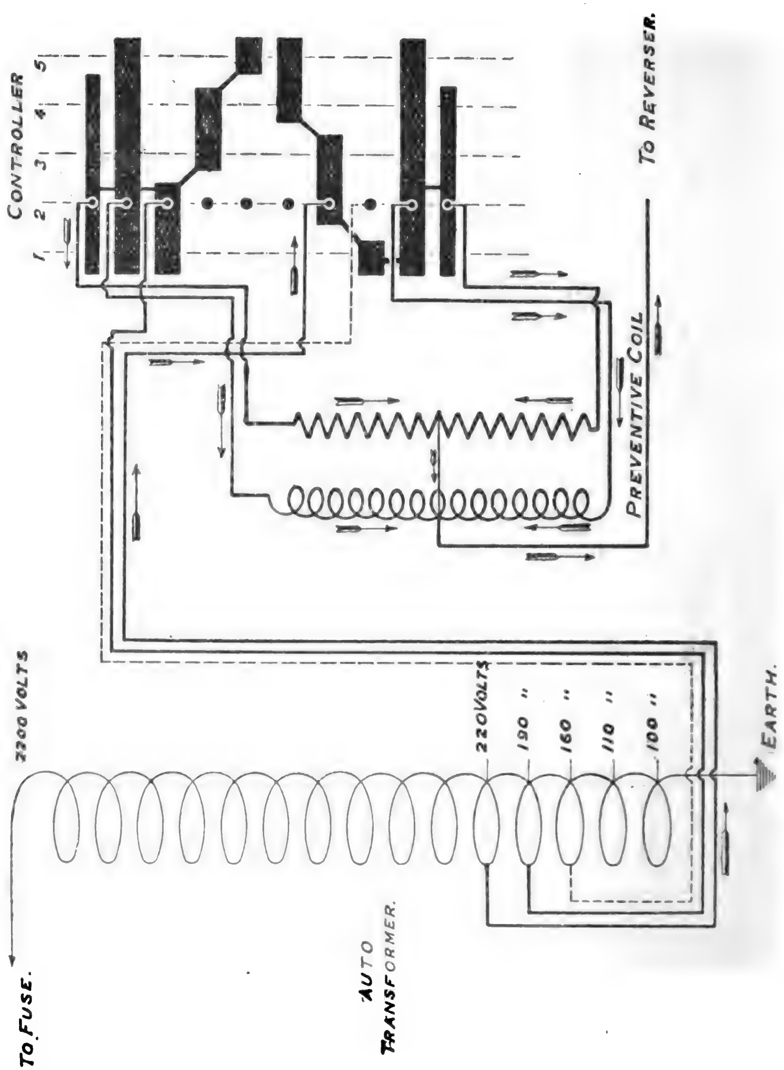

FIG. 12.—Diagram showing Distribution of Current with Controller in Second Position.

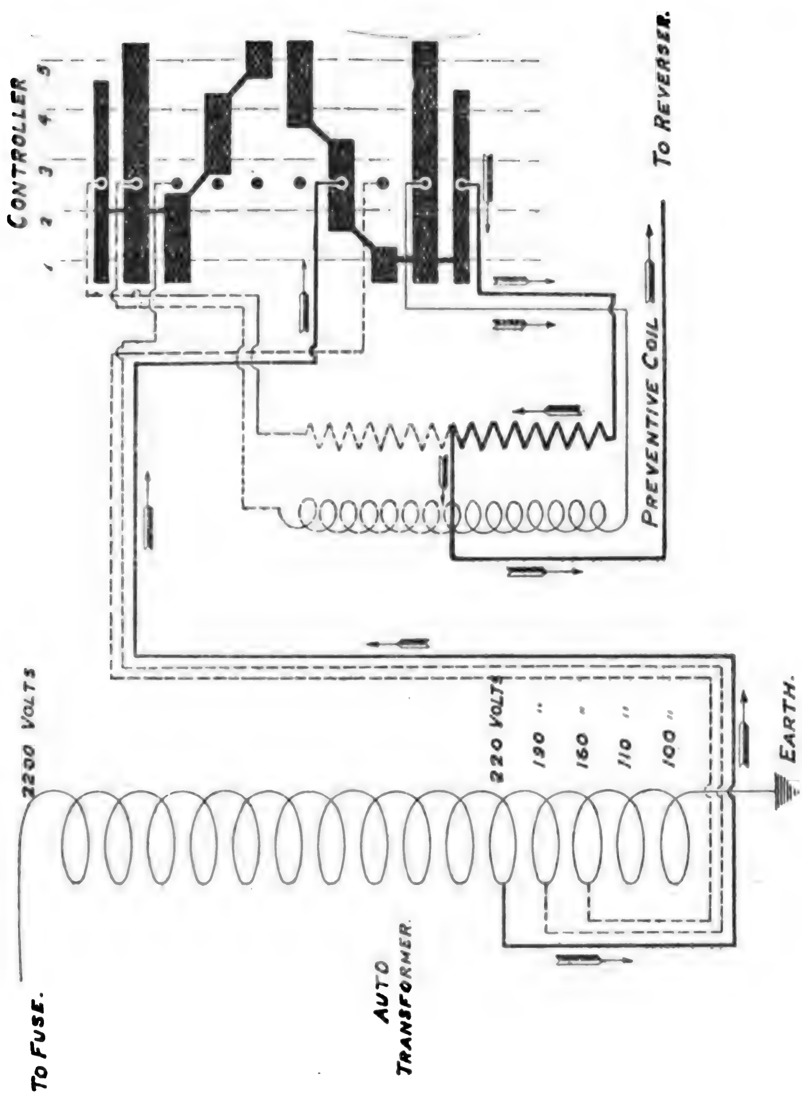

FIG. 13.—Diagram showing Distribution of Current with Controller in Transition from Second to Third Position.

For tramcar equipments it is necessary that the controllers be operated by hand. Such controllers have been developed for operating series motors, and the diagram of the electrical connections is shown in Fig. 9. This controller is of the rotating drum type, having stationary fingers, and a little different from an ordinary tramcar controller for continuous current.

In order to prevent sparking and burning of the controller contacts

a preventive coil and preventive resistance are used; the relation between the various pieces of apparatus for any notch of the controller may be seen in Fig. 10.

When the controller drum is rotated from one notch to the next, one leg of the circuit is interrupted. In Fig. 11 this transition is shown, and it may be noted that only a small current passes through the preventive coil; the main volume of current for the motor passes through the preventive resistance.

When the controller is on the last notch, or full running position, the preventive resistance is disconnected from the circuit.

DISCUSSION.

Mr. Pearce. Mr. S. L. PEARCE (Chairman): I would be very glad if Mr. Schoepf would enlarge on the points of difference between the straight series single-phase motors and repulsion motors for the main line working and their relative advantages and disadvantages. The fact that the engineers of both the General Electric Company of America and the Westinghouse Company favour the former for railway work is rather noticeable as against the Continental firms' advocacy of the latter. It would be interesting to the meeting to know of any of the technical considerations which induced the engineers for the London, Brighton & South Coast Railway to adopt the Winter-Eichberg system of single-phase motors.

Mr. Cramp. Mr. W. CRAMP: To those who, like myself, have had the opportunity of seeing the single-phase locomotive at Old Trafford, the paper is especially interesting. For in this equipment one is struck by the perfect control, all operated from a tiny box on the dashboard, not one quarter the size of the ordinary tramcar controller. The beautiful way in which the electro-pneumatic switches close in proper order, and the absolutely perfect commutation under most trying conditions, are points which appeal to any one acquainted with traction problems. While we are all much indebted to Mr. Schoepf for his paper upon this ingenious series-motor equipment, I think the author is not quite fair to other types of single-phase commutator motor. I classify the various types of single-phase commutator motors as follows: (A) 1. Plain series. 2. Neutralised series (Westinghouse, Finzi, &c.) 3. Compensated series (Eichberg). (B) 1. Plain repulsion. 2. Neutralised repulsion. 3. Compensated repulsion (Latour). In this classification "(B) 1" is the original repulsion motor consisting of laminated alternating-current field with direct-current type armature and commutator, the brushes being short-circuited and set at an angle to the main field. Thus the excitation is not provided by the armature. The motor "(B) 2" can fairly lay claim to the advantages of both series and repulsion type. Now in comparing these various motors we have to consider six points—viz.: (1) Torque, (2) efficiency, (3) power factor, (4) starting conditions, (5) commutation, and (6) frequency. Taking these points in order, all the motors have the same torque characteristics, and in respect to torque per ampere they are about equal. With regard to efficiency, the compensated and neutralised motors are

usually slightly less efficient than other forms by the loss in their extra windings. The power factor of the repulsion motor is not quite so good as that of the straight series motor, but, of course, compensated motors are the best in this respect. At starting, the repulsion motor is quite as good as its rival, possessing excellent torque and accelerating smoothly and well; but it is in commutation that the series motor scores, as salient poles can be used, while a small air-gap and a resultant practically rotating field are essential for the repulsion motor. Lastly, for different frequencies the repulsion motor is far better, since for anything like reasonable efficiency at full load the series motor has to run well above synchronism, while the repulsion motor only runs at about three-quarters synchronous speed. Thus repulsion motors can be built for frequencies of 40 ∿ per second, in which case series motors are almost out of the question. This is of special importance in England, where we may wish to use alternate-current commutator Mr. Cramp.

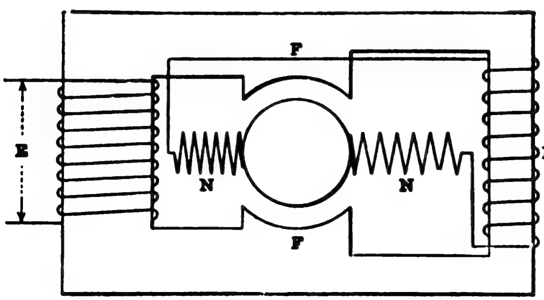

FIG. A.

motors in connection with ordinary lighting circuits. Coming now to the matter of control, almost any system suitable for one type of motor is suitable for the others; but we have a choice of systems with repulsion motors that does not exist with series machines. For we may effect the control by rotor resistances, as is done in the Schüler motor and the ordinary induction motor. It is this which enables us to put a high voltage on the stator and get rid of the bulky transformer. I do not understand Mr. Schoepf's statement that a given repulsion motor must have its field winding adapted to one voltage. What is the objection to grouping a multipolar field in series or parallel for different pressures? I should like to call attention to the use of the "preventive coil," which seems to fulfil the same function as the resistance coil in the ordinary accumulator switch.

Mr. E. W. COWAN: Eight years ago Mr. Atkinson and I carried out experiments on similar problems. We could not get over the excessive sparking, although we obtained variable speed and variable torque. Mr. Cowan.

Mr. H. E. O'BRIEN: Does the author use air-cooled transformers? I think the man who is responsible for the repair and maintenance of repulsion motors arranged as Mr. Cramp suggests, with tappings on the 6,000-volt stator winding, would be likely to go stark, staring mad. Mr. O'Brien.

Mr. Cramp.

Mr. CRAMP: My proposed arrangement is shown diagrammatically for a 2-pole motor in Fig. A. The high-tension mains are connected to the coil E, which excites not only the field FF, but also the secondary coil B in series with the usual armature and neutralising coils NN. It seems to me that by this arrangement excellent commutation can be secured with a good series characteristic, while a high-tension stator winding E is possible without any fear of the attendant being driven stark mad.

Mr. Schoepf.

Mr. SCHOEPF (*in reply*): I think Mr. Pearce has been misinformed in stating that the Continental firms advocate the repulsion motor, as I have been able to find only one, all of the others advocate series motors; some of which have modified windings.

I know of no technical considerations which induced the engineers for the L.B. & S.C. Railway to adopt the Winter-Eichberg system of single-phase train equipments, and think the railway officials are the only ones informed as to their reasons for this decision.

In reply to Mr. Cramp, I wish to say that his classification is not correct, as there is no fundamental difference between neutralised and compensated motors; the only difference is in the choice of a commercial name. In my opinion the word "neutralised" correctly expresses the function of this winding.

Mr. Cramp has made a careful and fair comparison of the performance of the two types of single-phase motor, but I must take exception to his conclusion under item 6. If you will consider the characteristic curve in Fig. 4, you will find that the synchronous speed is 600 r.p.m., full-load speed 535 r.p.m., and free-running speed 1,325 r.p.m. Compare this with a similar repulsion motor, and you will find the full-load speed to be only one-half synchronous speed, so that the latter is the same as the free-running speed. This is done because the commutation of the repulsion motor is best at synchronous speed owing to the rotating field.

The advocates of the series motors have designed their motors to operate at 25 periods, which is a recognised standard. I think you will find the demands so isolated for motors to operate on 40 periods that the manufacturers are quite justified in hesitating to develop a motor for this frequency, as the performance of either type of motor is inferior at the higher frequency.

If Mr. Cramp will consider the conditions of the Indianapolis and Cincinnati line he will see wherein the repulsion motor is less flexible so far as change in voltage is concerned.

In reply to Mr. O'Brien, I may say that air-cooled transformers are cheaper and equally good as oil transformers on voltages up to 6,000, but above that I think oil transformers should be used, because of their superior insulation, as they are less liable to absorb moisture, which must be borne in mind in this country. My personal preference is for all oil-insulated transformers.

S

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1905—1906.

EXPLANATION OF ABBREVIATIONS.

[P] signifies a reference to the general title or subject of a Paper.

[*p*] signifies a reference to a subject incidentally introduced into a Paper.

[D] signifies a reference to remarks made in a Discussion upon a Paper, of which the general title or subject is quoted.

[*d*] signifies a reference to remarks incidentally introduced into a discussion on a Paper.

[*Ref.*] signifies a reference to the place of publication in the Technical Press of a Paper read at a Local Section, and not yet printed in this Journal.

Note.—The lists of speakers in the Discussion upon any Paper will be found in the Table of Contents at the beginning of the volume.

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